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IMPACTS OF TILE DRAINAGE

R. A. C. PROJECT NO. 152 PL

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ABSTRACT

The objective of the research described in this report is to investigate the hydrology of the agricultural drainage process, and its impacts on the land phase of the hydrologic cycle. Work included the development of an annotated bibliography following an extensive literature review. Statistical tests were performed on flow data in an attempt to identify trends in the data which could be attributed to the drainage process. Finally, the impacts of both tile drainage at the field level and ditch drainage at the small basin level were considered and analysed through the use of a physically-based hydrologic model capable of simulating the drainage process continuously through the frost free period. Required input includes field and tile geometry (field length and slope, number and spacing of drain tiles, depth of tile), soil characteristics (depression storage capacity, depth of ploughed layer and depth to impervious layer), groundwater parameters (saturated hydraulic conductivity and drainable porosity), and meteorological data (hourly rainfall and mean daily temperature). Output includes soil moisture storage, groundwater table height, subsurface hydrograph and contribution to surface runoff.

The model has been tested on two fields in southeastern Ontario. The data collection program and the techniques for the practical measurement of physical parameters for the test fields are described. The model successfully replicates observed flows and water tables for two distinct soils and for a wide range of antecedent conditions and storm rainfall. Applications of the model to the evaluation of the hydrologic impacts of tile drainage are discussed.

1.0 INTRODUCTION

1.1 Overview of Agricultural Drainage

Agricultural land drainage involves the enhancement of the natural drainage process to remove excess water from farmland, thus increasing its productivity. In Ontario, two levels of agricultural drainage works can be identified: (i) tile or ditch drains at the field level; and (ii) municipal drains.

Tile Drainage

Tile drainage consists of a network (usually systematically controlled) of clay tiles or, more commonly, perforated plastic pipe, installed at a uniform depth below the crop root zone. Excess water percolates downwards and moves under the influence of gravity to the drain, where it is removed from the field (Figure 1-1).

The drains effectively keep the ground water table below the root zone, allowing aeration of the root zone, and preventing stress to the crop. In addition, the tile drains lower the spring water table more rapidly than would natural interflow or evaporation - thus allowing the farmer access to his field for earlier harrowing and seeding.

Municipal Drains

Municipal drains are either new or improved existing channels which convey the excess water from the fields to receiving creeks or rivers (Figure 1-2).

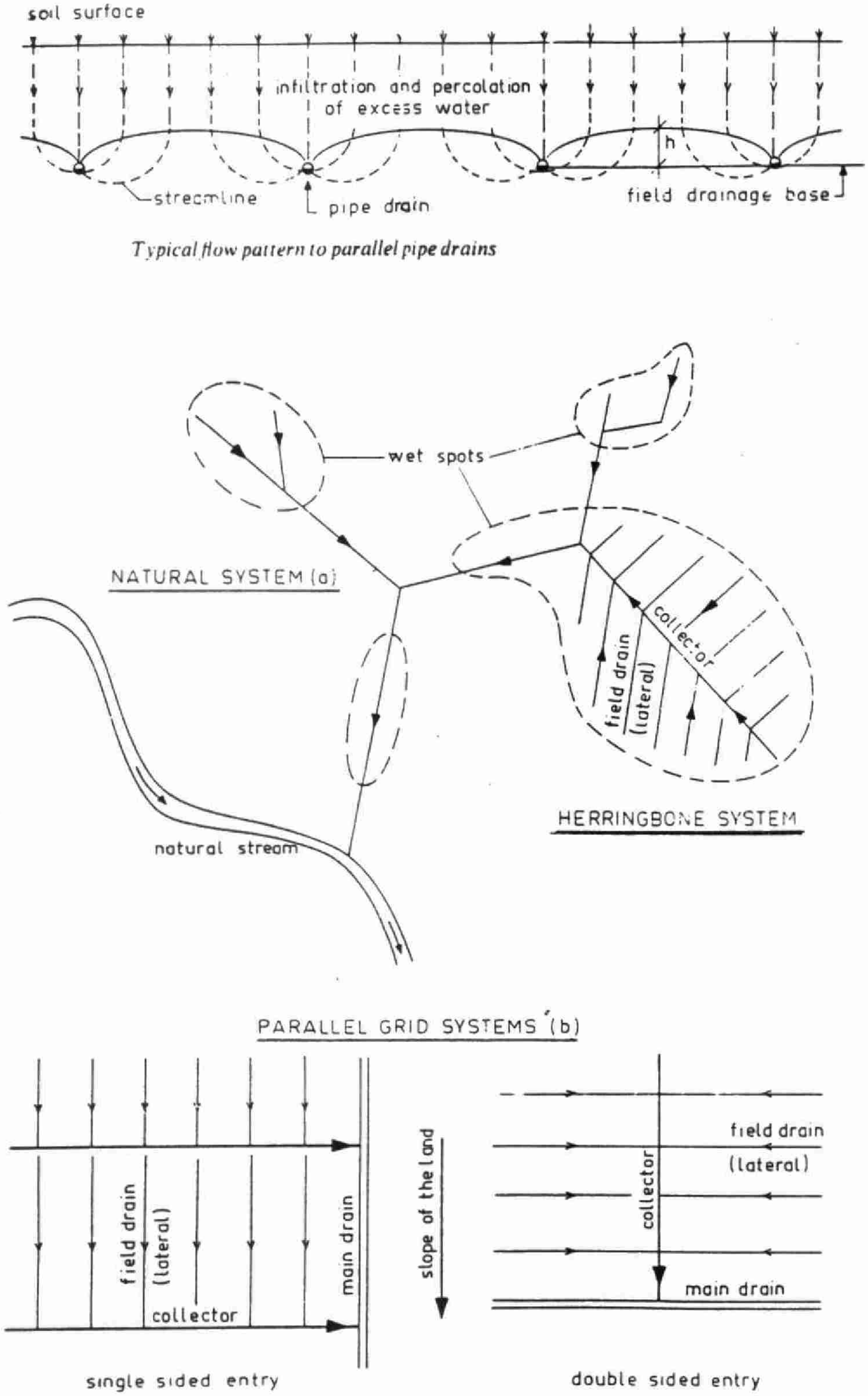
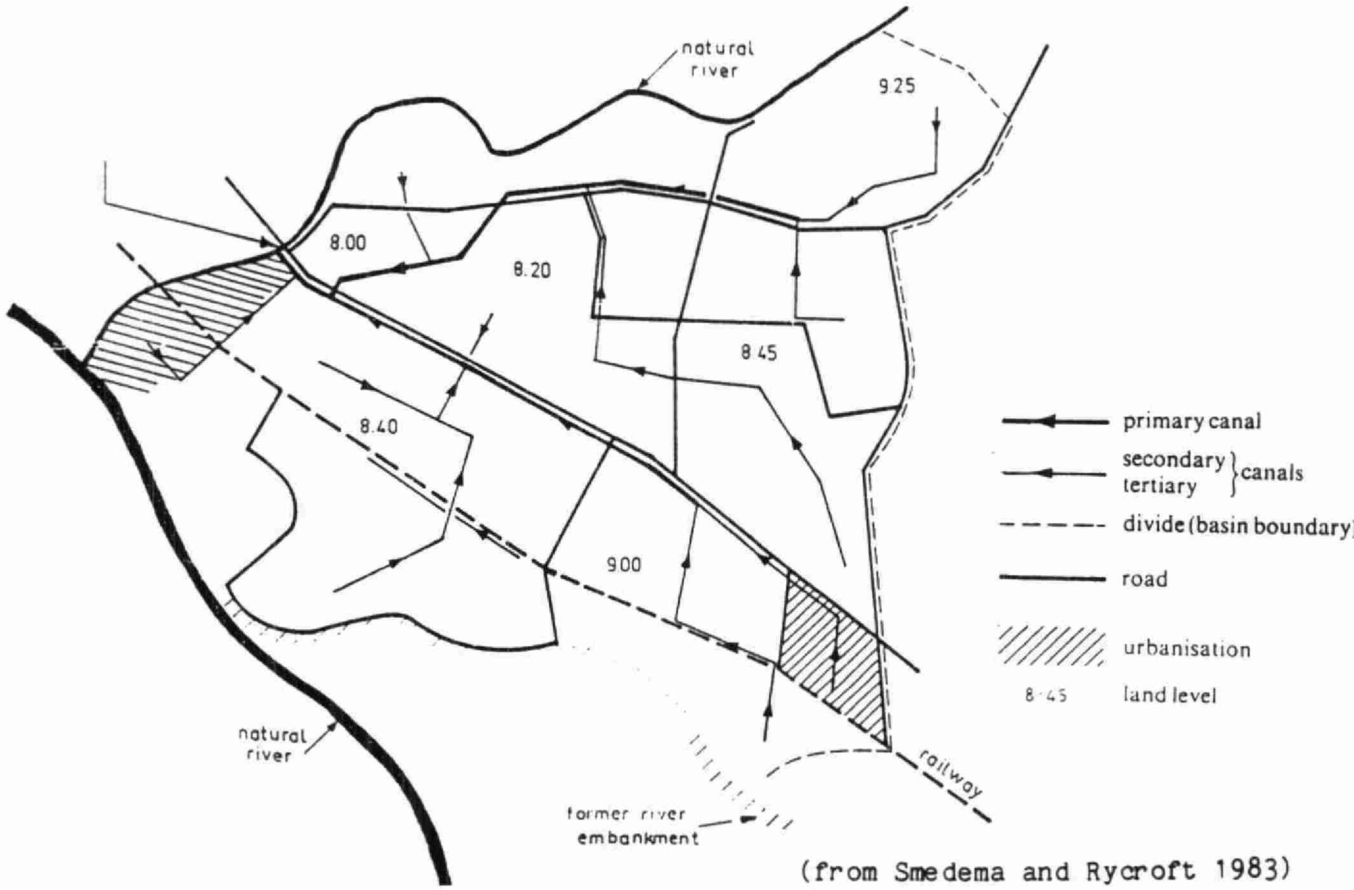


Figure 1-1 Illustration of tile drainage (Smedema et al. 1983)



(from Smedema and Rycroft 1983)

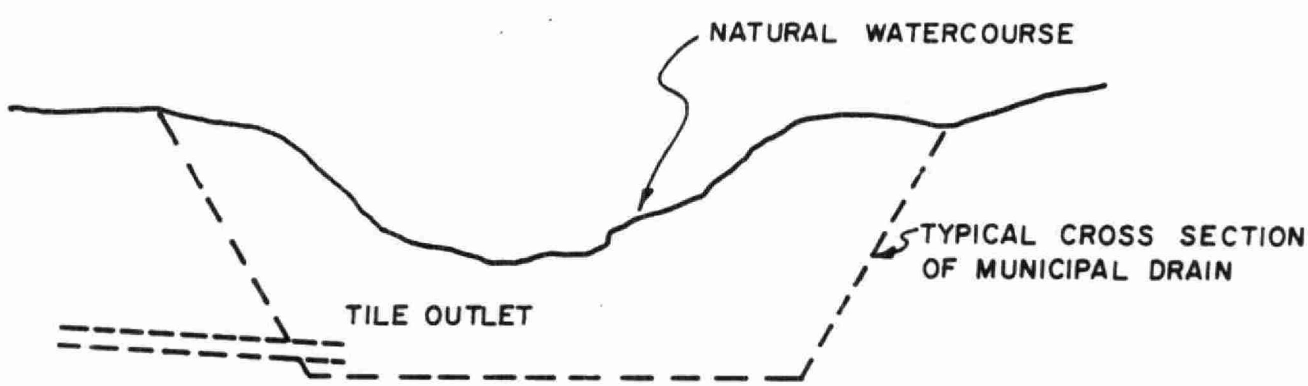


Figure 1-2 Illustration of municipal drains

In Ontario, improvements to the natural drainage process began as early as the original clearing of the land for agriculture in the early 1800's. The intensity of drainage improvement increased extensively, however, during the 1960's and 1970's. This was primarily due to the installation of tile drainage, and to increased grants available under the Drainage Act and the Special Drainage Assistance Programme.

1.2 Study Background and Terms of Reference

1.2.1 Need for Research

As identified in the proposal for the study, the need to increase agricultural productivity through land drainage is obvious to all those in the agricultural sector. Because less than five percent of the total land in Canada is suitable for cultivation, the reclamation of cultivable land by drainage improvement will continue to accelerate. The effects of this drainage on those rivers and streams that receive waters from drained areas are not clearly understood, but they can be adverse. In particular, they may result in increased peak flows and reduced low flows. The increased peak flows cause erosion and flooding and downstream land owners often demand expensive flood control structures to restore pre-drainage flood levels. The reduced low flows result in impaired water quality conditions and downstream users may demand expensive water storage structures to increase low flows to pre-drainage conditions. Concerns over both these effects has led to pressure to delay, defer and cancel drainage projects. However, there is not general agreement on the hydrologic impacts of tile drainage and often claims by both proponents of, and objectors to, drainage projects are speculative.

Because of this lack of understanding of the overall hydrologic response to agricultural drainage, there is an urgent need for research to evaluate the impacts of drainage and for the dissemination of knowledge as

it becomes available to assist in the planning of drainage projects which are technically, environmentally, and economically sound.

The section which follows outlines the terms of reference for the study as originally proposed to the Ontario Ministry of the Environment.

1.2.2 Objectives of the Work

The objectives of the work as set out in the proposal were:

- to perform statistical analyses to detect the effects of agricultural drainage on peak flow and dry weather flow;
- to develop, test and calibrate a physically-based model which is capable of simulating the hydrologic response of agricultural drainage on a basin scale;
- to undertake field studies to calibrate and test the model;
- to use this model to evaluate the effects of tile drainage and open ditches on peak flows and dry weather flows; and
- to provide guidance on the use of the model and to make the model 'user-friendly'.

1.2.3 Methodology

The methodology, as set out in the proposal, was as follows.

Preliminary Analysis

A preliminary investigation will be undertaken on the available data base to detect any changes in the hydrologic regime of a field/basin due to the installation of agricultural drains. Statistical techniques such as time series analysis, non-parametric tests for trend, homogenity and independence will be involved at this stage.

Model Development

A tile and drain model which can be used to evaluate the impact of agricultural drains at the basin scale has not yet been developed. An extensive literature review will be undertaken to assess the nature of the problem of modelling subsurface flow and evapotranspiration. Recent developments in process modelling of subsurface runoff and evapotranspiration will be reviewed and incorporated into an existing tile-drain model. There is a wealth of information available on both the processes and the parameters of the physically-based models used to simulate these processes. Indeed, a not insignificant amount of information is available as a result of the work of Agriculture Canada soil scientists. (Topp et al. 1980; Topp and Davis 1982)

The model (either developed or modified from an existing model) must be physically based and its parameters must have pertinent meanings in terms of hydrologic processes. The model will be capable of running continuously and include accounting, infiltration recovery, interflow storage and routing, deep groundwater storage, tile and channel flow and

routing, detention and depression storage, surface runoff routing and evapotranspiration.

Field Study

One of the tile-drained fields in the South Nation River basin will be instrumented to collect meteorological, groundwater and tile flow data for model calibration and verification. Reliable historical data before the installation of agricultural drainage will be employed to detect the changes in those model parameters which characterize the field behaviour. Comparison of the hydrologic parameters will reveal the change of hydrologic regime due to agricultural drainage.

Once the models are calibrated, realistic meteorological data can be generated and applied to the models in order to determine the effect of agricultural drains on peak flows and dry weather flows.

Basin Wide Analysis

After establishing the drainage model for a field, the model will be extended to a basin. A similar assessment will be undertaken on the available data base to evaluate the effect of agricultural drains on peak flows and dry weather flows at a basin level.

1.2.4 Phases of the Work

Phases of the work, as set out in the proposal, were as follows.

1. Meet with MOE officials to arrange liaison and reporting schedule and to review objectives and phases of the work.

2. Collect all usable data.

3. Undertake a world-wide literature review on the hydrologic effects of land drainage and on the models used to simulate the moisture transfer processes in the unsaturated zone.

4. Review knowledge and existing models for groundwater flow in the saturated zone.

5. Perform statistical analyses on the available data.

6. Undertake field studies to collect data.

7. Apply the results of 3 and 4 to improve and modify an existing tile drainage model which can be used to simulate the tile flow from a tile-drained field. Calibrate this field model using continuous data.

8. Incorporate the field model developed in 7 into a continuous basin model. Calibrate this basin model using continuous data.

9. Document both field model and basin model.

10. Develop a 'user-friendly' interface.

11. Prepare and submit final report.

2.0 LITERATURE REVIEW

2.1 Annotated Bibliography

The annotated bibliography (Queen's University 1985), was developed during the worldwide literature review on the hydrologic effects of land drainage and on the models used to simulate the moisture transfer processes in the unsaturated zone. With over 400 entries, it is anticipated that the bibliography will prove useful to other researchers in the field of agricultural drainage.

The bibliography concentrates on recent papers and publications in the field of agricultural drainage research and related topics, and spans the period 1970 to 1985.

Because the bibliography was developed primarily to assist in the present research, some topics, which may be regarded by others as important depending on their interests, have been excluded or dealt with in a less detailed fashion. Topics which were not included are: drainage of peatlands for agriculture; detailed treatment of numerical modelling in porous media; and detailed treatment of thermodynamic modelling or heat flow and mass transfer in soils.

Abstracts were collected through use of the Engineering Index, the CENV database through QL Systems Ltd., recent journals, publications and texts, and contact with other researchers in Canada and the United States.

The annotated bibliography exists in two forms: (i) a hard copy printout; and (ii) as a database on IBM compatible floppy disks.

The bibliography is divided into 11 subcategories with papers ordered by year within the following subcategories.

1. Effects of Land Drainage
2. Evapotranspiration
3. Drains and Water Movement
4. Agricultural Watershed Modelling
5. Frozen Soil and Infiltration during Melting
6. Soil Moisture Measurements
7. Soils and Moisture Movement within Soil Profile
8. Infiltration
9. Numerical Modelling of Processes within Soil Layers
10. Depression Storage
11. General

In addition to these subcategories, ordered by year of publication, two indices were included. The alphabetical author index lists the reference numbers for all the papers for each author within the database. The journal index lists all the journals or proceedings in an abbreviated form referred to in the data base. It is necessary to use this abbreviated form when using the search program to look for a paper using a journal name.

If the user has access to an IBM compatible microcomputer, it is suggested that the disks be used as the search procedure is considerably simplified. The database is contained on seven disks which form data files written under dBASE III. These files, when used in conjunction with the special menu driven search program, allow a user to access abstracts by author, key words, title, year of publication or journal and to selectively print out those abstracts of interest. The search program does <u>not</u> require extensive familiarity with microcomputers.

2.2 Impacts of Drainage on Downstream Flows

The intent of field drainage is to modify the natural soil-water regime at the field level; however, to achieve this, modifications to a drainage basin beyond the field level are necessary. Tile drains or field ditches must drain to larger channels (municipal drains) with larger cross sections and slopes than natural channels. These drains provide temporary storage for the increased volume of water and remove it quickly to keep the frequency and duration of saturated field conditions to a minimum.

If a representation of the physical system is considered (Figure 2-1), the action of drainage becomes apparent; the natural hydrologic process can be represented by input and output elements connected by storage and routing elements. Agricultural drainage operates on these storage and routing elements.

In general, it is desirable to make the storage components smaller (the exception is channel storage which is usually increased as channel cross sections are enlarged) and to make the routing or transmission elements behave more rapidly. This is achieved by increasing the slopes of drainage ditches, decreasing the roughness through the removal of natural obstructions, shortening flow paths and enhancing soil porosity. The result is that a larger volume of water will be removed from the land in a shorter period of time.

A hydrograph for a drained area will exhibit higher peak flows and a faster recession than the undrained case. Higher velocities and discharges could lead to increased erosion and frequency of flooding in drainage channels and receiving water courses.

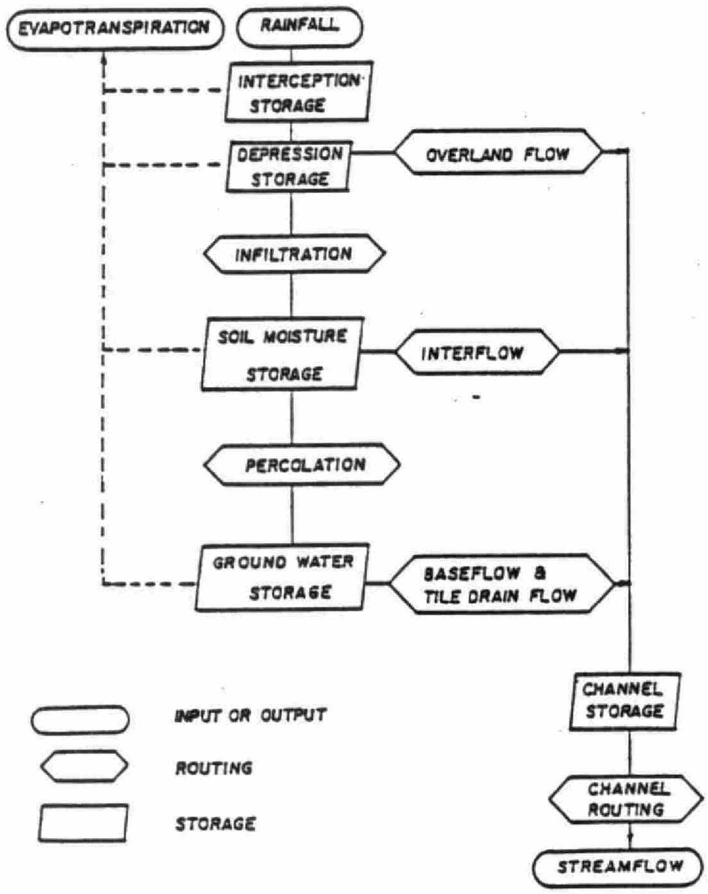


Figure 2-1 Representation of the physical system

The effects of drainage can also be viewed in a probabilistic sense (Figure 2-2). The physical system represented in Figure 2-1 operates on the input (the rainfall/snowmelt time series) and converts it and its associated frequencies to an output (flows and volumes). Drainage alters the operator and hence alters the frequency characteristics of the output. Although the frequency of crop inundation or root zone saturation in the field will be reduced, the frequencies of peak flows and volumes downstream are likely to increase.

2.2.1 Evidence of the Effects of Drainage on Flows

Unfortunately, where data exists to support the premise of increased downstream flows, it is usually site specific and often sketchy. Watt and Paine (1985) attest that some knowledge can be gained by analogy. The actions of removing water storage elements and increasing the efficiency of transmission elements do indeed increase peak flows and volumes for a specific event or increase frequencies of higher flows for a series of events for two cases that are well documented; these are urbanization and deforestation. Similar effects will result from reduced storage and faster transmission through the implementation of drainage projects.

The actions of urbanization and deforestation on a watershed are more drastic 'shocks' than agricultural drainage. If the impact of an operation is proportional to its magnitude, urbanization and deforestation could be considered as first order shocks. Agricultural drainage is then a second-order shock and consequently, its impacts will be more difficult to observe.

Recent literature reviews were performed by the National Hydrology Research Institute (Prasher 1982) and by Irwin and Whiteley (1983). These reviews focused on a detailed examination of papers and studies dealing

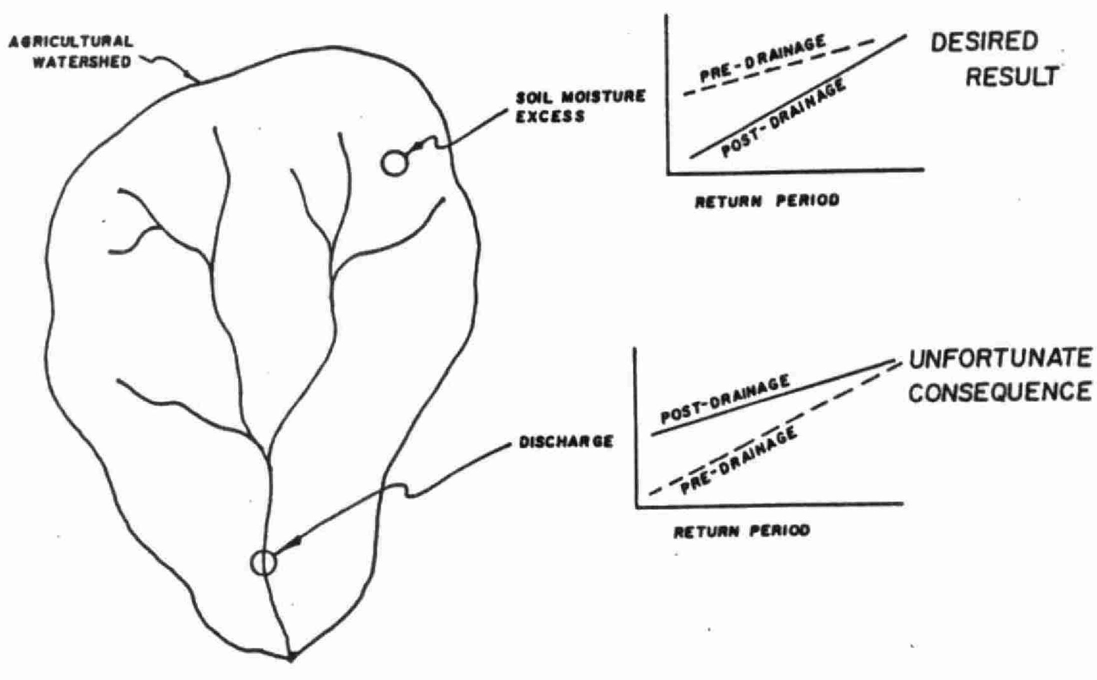


Figure 2-2 Impact of drainage on downstream peak flows

with the effects of land drainage on streamflow. These studies noted that the hydrology of drainage is complex and that the effects of land drainage are often masked by other land use or climatological changes with time in the watershed.

The findings of the studies lead to the following observations.

1. Land drainage can have a significant impact on stream hydrographs. The effects of channel improvements overshadows effects due to draining depressions or modifying the soil-water regime by tile drainage.

2. The magnitude and timing of impacts are variable; they depend on the work done, its location in the watershed, and the physical characteristics of the basin.

3. Existing models to simulate the drainage process are often oversimplified and possess incorrect or inadequate submodels.

4. Knowledge at the field level and of processes in the unsaturated zone is lacking.

5. Tile drainage provides storage capacity in the soil profile. This storage acts as a reservoir which fills and reduces surface runoff for low intensity storms but will have only a minimum effect for medium and high intensity storms.

6. Major drainage channels in watersheds with large marshes or bogs increase floodpeaks 60 to 100 percent.

To obtain evidence of the impacts of drainage on flows, there are two general approaches. The first is to examine flow records for trend. The second method is to develop a hydrologic model which is capable of

accurately simulating the response of the system and then to operate the model with typical meteorological inputs and with model parameters corresponding to drained and undrained conditions.

2.2.2 Trend Analysis to Obtain Evidence of Drainage Impacts

As indicated above, one method to obtain evidence of drainage impacts is to examine flow records for evidence of non-stationarity that is statistically significant. This non-stationarity could be in the form of either a jump or a trend which may be evident in one or more statistics of the flow series (e.g. mean, maximum, minimum) or to the frequency distribution of one or more of these statistics. For reliable trend analysis, a long period of flow record (> 25 years) for a basin in an undrained state followed by an equally long period of record for the same basin in an extensively drained state would be ideal. Over the total period, all other factors (average precipitation, temperature, etc.) should be constant. Generally, a much shorter period of record exists with a large number of factors changing and with the drainage process itself extended through the period of record. The following factors must be taken into account when examining the record statistically and looking for trend:

- the influence of climatic changes,
- the rate of drainage activity,
- the location of the drainage and its time of implementation within the watershed,
- the type of drainage (tile vs. outlet drain construction),
- the influence of changes in crops grown and agricultural practices (often a direct result of drainage), and
- physical changes in the watershed with time that have nothing to do with drainage (sedimentation, urbanization, river crossings, etc.).

Because of the random nature of flows, a lengthy period of record,

often with very extensive drainage works, is required to obtain statistically significant and identifiable trends. Even if a trend can be identified, the unfortunate fact remains that the results are site specific. Appreciation of the result of drainage without an understanding of the intricate subprocesses limits the ability to transfer the results to other locations.

Recent research in the United Kingdom (Bailey 1981) appears to illustrate a relatively successfully application of trend analysis. Twelve catchments in Ireland were examined, each with an average of 10 years of record prior to and after drainage. Flood peaks were examined and analysed for pre- and post-drainage conditions (Figure 2-3). The responses of the catchments were substantially altered by tile and mole drainage in fields, ditching and improvement of main arterial channels and river controls.

Figure 2-4 illustrates the results of a split record test performed to assess the possibility that the frequency shift may have been due to climatic changes over the period of record, i.e. increased post drainage flows might be due to wetter, more flood producing weather having occurred in the post-drainage period than the pre-drainage period. The record on the Brosna (drained prior to 1955), which was unaltered over the periods in question, was divided into the same pre- and post-drainage periods as recorded on the Killimor River. Because the frequency curve for the Brosna is virtually identical for both periods of record, the frequency shift on the Killimor cannot be attributed to a change in climate.

2.2.3 Modelling the System to Determine Drainage Impacts

Ideally, a mathematical model to represent the basin in question should have submodels for each storage and routing function. Following calibration and verification of the model using observed data, the model

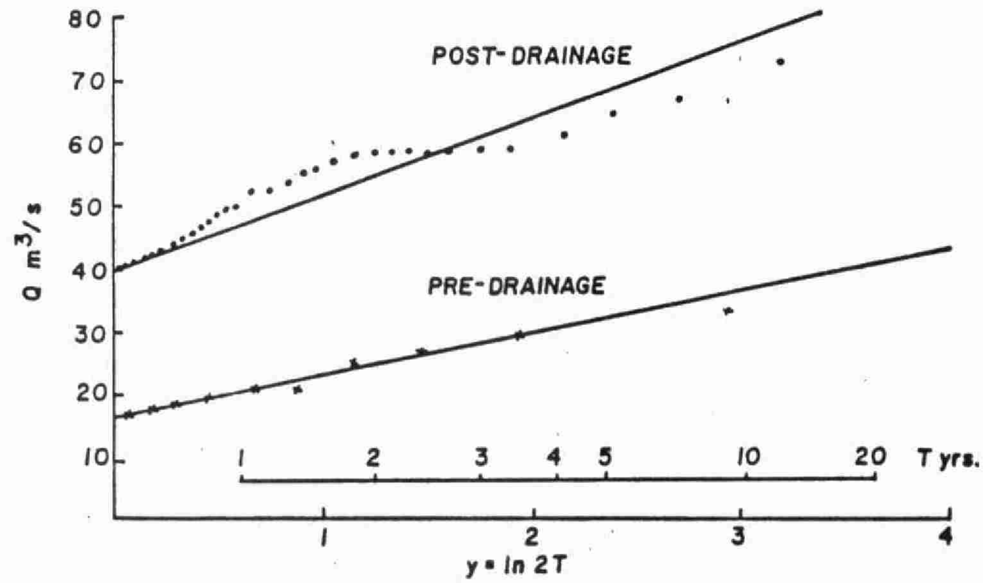


Figure 2-3 Pre- and post-drainage Q-T relation for the Nenagh Catchment (Ireland) 318 sq. km.

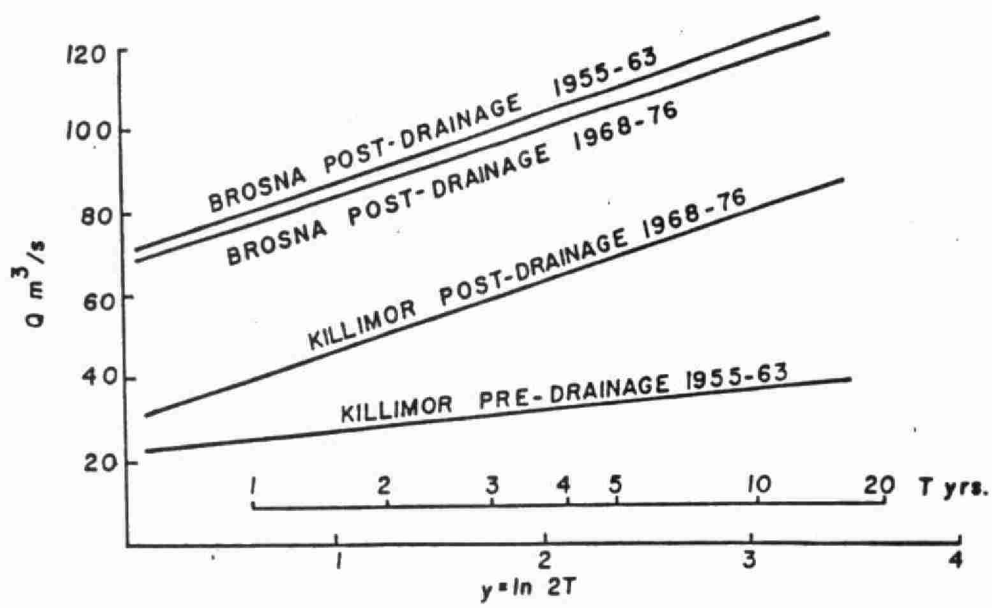


Figure 2-4 Split Record Test of the River Killimor 206 sq. km.

parameters are changed to simulate drainage conditions. The model is then applied in both the 'natural' and 'drained' states for the same input time series and the results compared. Requirements to ensure that models will allow an accurate assessment of the impacts of drainage are listed below.

1. A first priority is long term monitoring both for a drained basin and a physiographically/climatologically similar undrained basin. Measurements must include discharge and water table heights at various points as well as meteorological data (temperature, precipitation).

2. Soilwater models which adequately simulate surface and subsurface drainage at the field level over an entire year should be developed and calibrated.

3. The combination of 2. with standard routing routines to create a basin-wide model capable of simulating various types of drainage works in various locations will permit the evaluation of the effects of these works.

3.0 STATISTICAL ANALYSIS OF FLOW TRENDS IN DRAINED AREAS

3.1 General Approach

The use of statistics or a trend analysis to detect changes to the hydrological cycle as a result of drainage activity requires the examination and comparison of two data sets. First, streamflow records with a sufficiently long period of record during the drainage activities must be located and then analysed for trends in flow peaks, low flow levels and durations; and other hydrological anomalies which might be attributable to drainage activity. Secondly, if trends are found (or even if they are not), a comparison of the flow series should be made to some index of drainage activity with time. Unfortunately, this latter time series is somewhat difficult to derive. Although the Ontario Ministry of Agriculture and Food maintains an agricultural resource inventory which includes township maps detailing artificial drainage systems (both municipal drains and tiled fields are identified), these maps only provide one point on the drainage intensity index time series which is required. Perhaps the best index of agricultural drainage activity would be the annual expenditures in a township (or several townships in a watershed) directed towards petitioned municipal drainage projects. With these annual expenditures reduced to a common base (say 1987 dollars), an annual index of drainage intensity could be developed for a particular area.

An index of this nature does not exist. Its development would be expensive in time and manpower, as an examination of the Public Accounts in the National Archives in conjunction with an examination of individual township records would be required.

To minimize the expenditure of time unnecessarily and to avoid the development of several drainage intensity indexes which may not be

required, the researchers concentrated on the following trend analysis approach.

1. Uncontrolled streams and rivers in agricultural areas having a sufficient time base of flow records to permit a trend analysis were identified.

2. If a trend was identified, an examination of climatic records was to be made to determine if a climatological trend existed which could account for the trends in flow records.

3. Only if trends identified were independent of climate would the drainage intensity time series be developed from financial records.

4. the drainage intensity time series would be examined to determine a causal relationship with the flow records over the same time period.

3.1.2 The Flow Records

Following an examination of the Historical Summary of Streamflow Records (Environment Canada 1983) the gauging stations listed in Table 3.1 were identified as potential candidates for trend analysis.

3.2 Summer Flow Analysis

3.2.1 Record Selection and Analysis

In an attempt to eliminate the masking effect that large spring runoff flows would have on the information contained in the lower flow time series, only summer mean daily flows (from June - November inclusive) were examined. To economize on effort and computer time only a portion of the

Table 3.1 Candidate stations for trend analysis

WSC No.	Station Name	Used for: Flow quantile approach	Used for: Auto-correlation test (Split sample)
02FF002	Ausable River near Springbank	*	*
02FC001	Carrick Creek near Carlsaruhe	*	
02HC009	East Humber River near Pinegrove	*	
02GD010	Fish Creek near Prospect Hill	*	
02GC002	Kettle Creek at St. Thomas	*	
02GD008	Medway River at London		
02GD004	Middle Thames River at Thamesford	*	*
02FE004	Maitland River near Donnybrook	*	*
02GA018	Nith River at New Hamburg		*
02GA010	Nith River near Canning		
02LB007	South Nation River at Spencerville	*	*
02FB007	Sydenham River near Owen Sound		
02GG002	Sydenham River near Alvinston		*
02HA006	Twenty Mile Creek at Balls Falls		*

rivers listed in Table 3.1 were analyzed. Because it was the higher flows and lower flows in the summer period that were of primary interest, the flow data was analyzed first to define the mean flow and the upper and lower quantiles of mean daily flow. The number of days in each year with flows above the upper quantile and below the lower quantile flow value were identified and summed. The number of days of high flow and low flow were ranked and a Spearman rank order correlation coefficient test for trend was performed. The intent of the test was to ascertain whether the number of

low flow days (high flow days) was increasing or decreasing significantly over the period of record.

In virtually all the rivers tested, a significant trend implying a reduction in the number of low flow days in recent time was apparent (Table 3.2). Similarly, although less significant, an increase in the number of higher flow days with time was noted.

3.2.2 Trends with Precipitation

The possibility exists that short term climatological changes may have induced trends in the precipitation volumes over the period of record which would affect runoff volumes. An increase in precipitation volumes with time could have lead to the findings in Table 3.2 (i.e., a decrease in the number of low flow days with time). The Woodstock climatological station was selected as a representative station for southwestern Ontario, and a trend analysis was performed on summer precipitation volumes from 1946 to 1982. A Spearman test for trend with a rank order correlation coefficient of -.48, indicated a significant downward trend over the period of record. This value corresponds to a Student's t of -3.22 which far exceeds the t value at the 1% level (-2.72).

This brief analysis indicates that the influence of precipitation trends on streamflow cannot be ignored. A more detailed analysis of precipitation trends in the London area was performed by Serrano et al. (1985). Through 5-year moving averages of precipitation amounts and streamflow on the Middle Thames watershed (Figure 3-1), this study demonstrated "the lack of trend of streamflow with time due to any cause other than variation in mean precipitation".

Table 3.2 Trend analysis on number of high flow and low flow days during summer months (June - Nov.)

Station Name	**Spearman Rank Order at 5% level**	**Correlation Coefficient lower quantile**	**Correlation Coefficient upper quantile**
Ausable River near Springbank	.31	-.40	.45
Carrick Creek near Carlsaruhe	.36	-.53	*
East Humber near Pine Grove	.36	-.24	.22
Fish Creek near Prospect Hill	.30	-.37	.52
Kettle Creek at St. Thomas	.48	-.62	.36
Middle Thames River at Thamesford	.33	-.39	.22
South Nation at Spencerville	.33	-.33	.16
Maitland River near Donnybrook	.33	-.67	.43

* Test not performed

3.2.3 Hydrograph Recession Analysis

If the drainage process does significantly alter the storage and transmission elements in a watershed to remove water more rapidly from the land, this impact should be evident in the recession limbs of hydrographs following rainfall events (Figure 3-2).

An approach to the examination of this phenomenon could take the form of the analysis of several sets of hydrograph recessions from each half of a split record and their comparison. This approach would be time consuming, particularly if records from several rivers were to be analysed.

An alternative technique was selected to examine these possible changes. The split records of daily flows (first half and latter half) were subjected to an autocorrelation analysis at lags of one day to ten days. If drainage effects were to be noted, it would be expected that flows from the earlier records (less drainage) would exhibit more persistence and hence exhibit a higher autocorrelation than records from a more heavily drained watershed. The drained watershed with its shorter travel times and limited system memory should exhibit a smaller autocorrelation at corresponding lag times.

Because of missing data, not all of the rivers identified in Table 3.1 could be analyzed. For the rivers which were examined no distinct pattern was identified. Table 3.3 displays the autocorrelation coefficients for 5 and 10 day lags for the first half and latter half of the periods of record.

Following this split record or screening analysis, two rivers were selected for a detailed examination of auto correlation on a yearly basis. Flow values from June to November in each year were examined for auto correlation at 5 day and 10 day lag periods for the Middle Thames River at Thamesford and for the South Nation at Spencerville. Figure 3-3

Table 3.3 **Split record screening analysis of autocorrelation coefficient**

Station Name	**Autocorrelation Coefficients (Record A/Record B)**		
	Record A/ Record B	**5 day lag**	**10 day lag**
Ausable River near Springbank	1946-65/1966-85	.39/.33	.25/.26
Middle Thames River at Thamesford	1947-65/1966-85	.29/.29	.14/.24
Maitland River near Donnybrook	1946-65/1966-85	.37/.42	.28/.33
Nith River at New Hamburg	1950-65/1966-85	.11/.23	.08/.17
South Nation River at Spencerville	1946-65/1966-85	.60/.54	.41/.39
Sydenham River near Alvinston	1948-65/1966-85	.38/.35	.27/.27
Twenty Mile Creek at Balls Falls	1957-70/1971-85	.16/.31	.12/.17

illustrates the autocorrelation function for a typical summer (June-Nov.) period for the South Nation river at lags 1 day to 20 days. Figure 3-4 displays the time series of the autocorrelation coefficient (for 5 and 10 day lags) over the period of record. For both the Middle Thames and the South Nation no significant trend was identified.

3.3 Trend Analysis Summary

Brief comments regarding the preliminary work performed for the examination of trend in the flow records are noted as follows.

1. The findings are inconclusive; either the effects of drainage are secondary or they are compensating. Effects of tile versus surface drainage may counteract each other once flows enter the receiving stream, changes in the synchronization of various runoff peaks within a watershed may obscure individual field level or subbasin effects. Finally, individual runoff events may behave differently under drainage but the net runoff frequencies and volumes may be relatively unchanged.

2. Any trends or differences are easily masked by larger scale physical or climatological changes, such as short term trends in precipitation volumes or low flow releases from river regulation.

3. Any examination of flow records for trend is time consuming, expensive in man hours and in computer time. In addition, there exists the difficulty in selecting the appropriate statistic to test for trend when the actual understanding of the processes and possible effects are unknown. For example, the examination of mean annual flows would be an inappropriate statistic to test to determine trends resulting from physical changes due to the drainage process. Indeed if a trend is identified, uncertainty will still exist as to the causative factors of the trend. For example uncertainty will remain as to whether the trend is in fact due to drainage, other physical factors, or is an artifact of the data manipulation process.

Following the preliminary analysis for trend - the need to understand the drainage process at the field level on an event by event basis was reinforced. Further efforts on the project were directed to the development of drainage simulation through the development and application of a physically based tile drainage model.

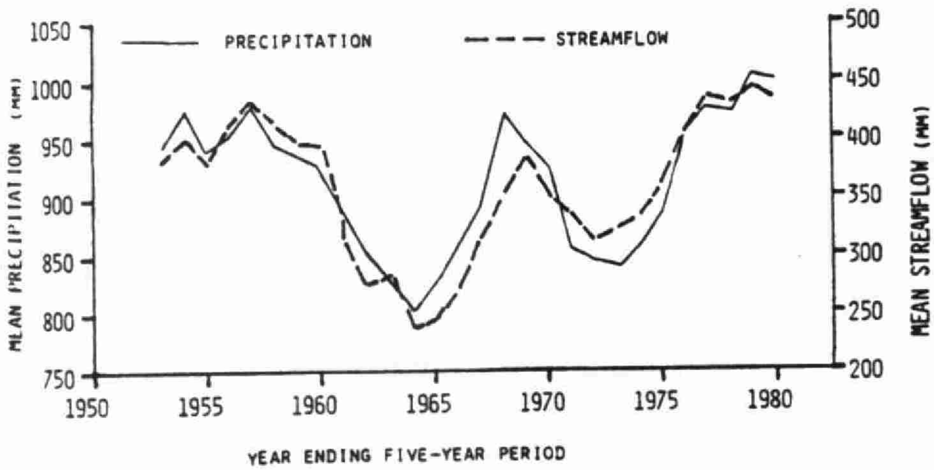


Figure 3-1 Five-year moving average amounts of annual precipitation and annual streamflow on the Middle Thames River watershed. (after Serrano et al. 1985)

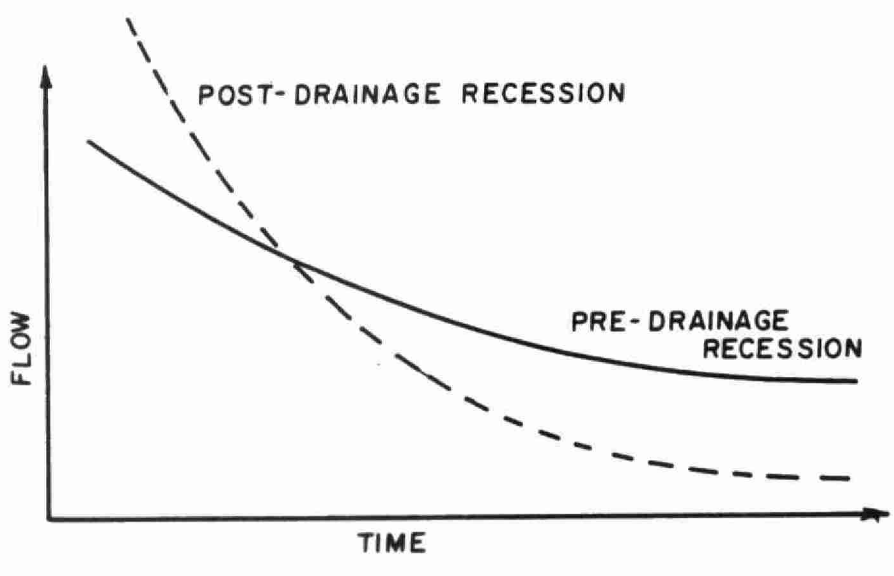


Figure 3-2 Predrainage and postdrainage hydrograph recessions

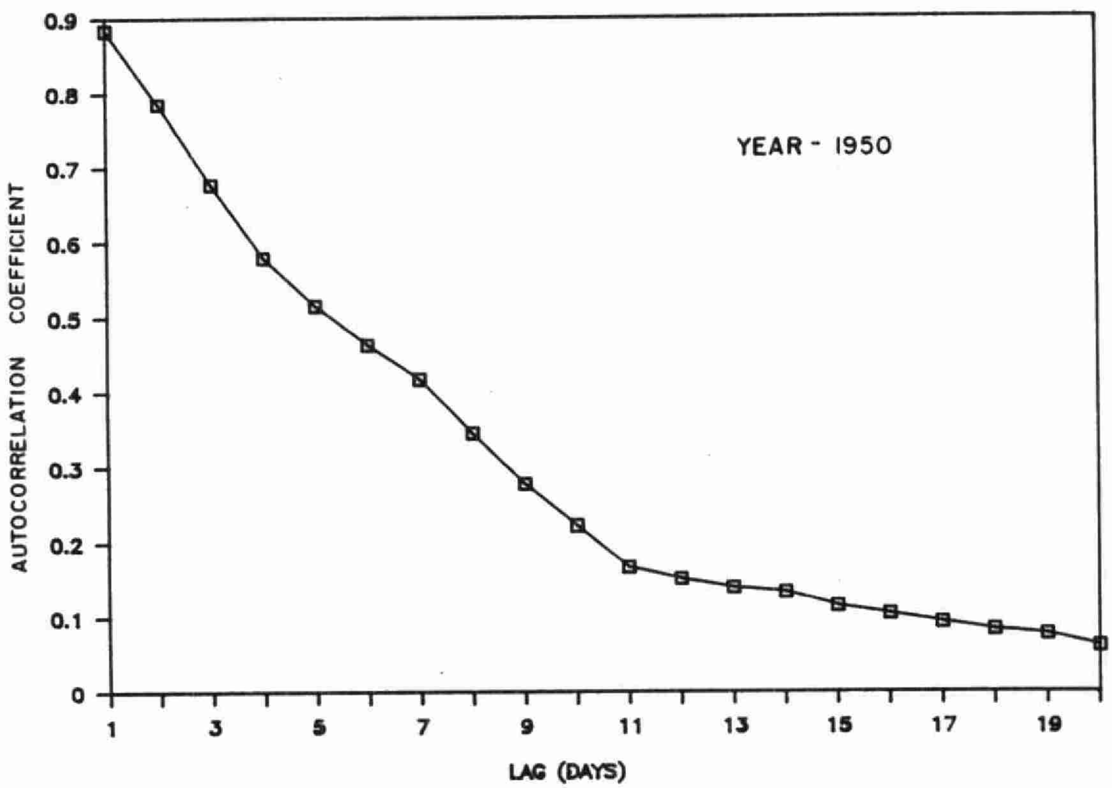


Figure 3-3 Autocorrelation function for a typical summer period (June - Nov.): South Nation River

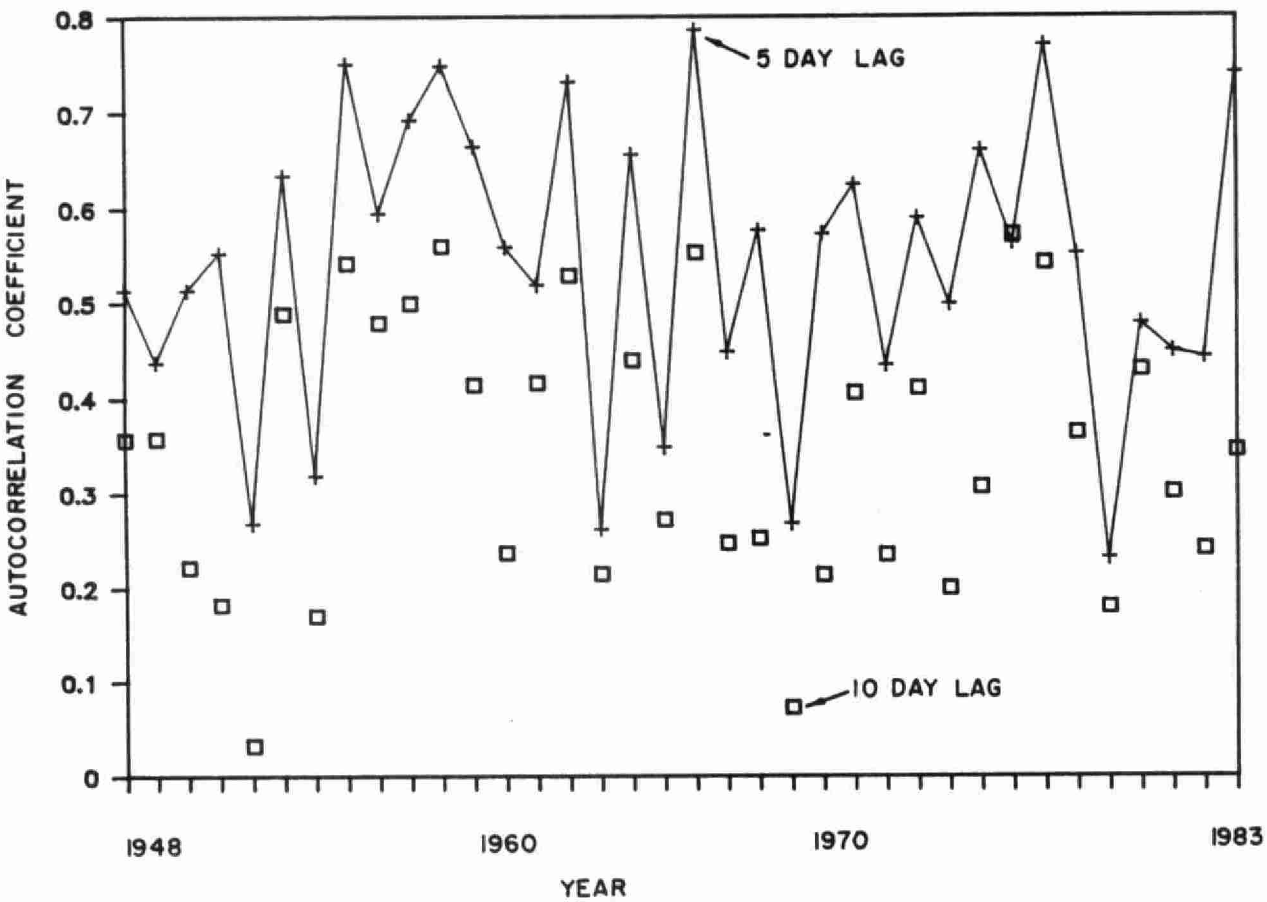


Figure 3-4 Time series of autocorrelation coefficient (5 and 10 day lags): South Nation River

4.0 FIELD STUDIES

4.1 The Test Fields

Tile runoff data was collected from two test fields to assist in the development of the model and to provide data for calibration and verification.

During 1986, the two tiled fields were instrumented for rainfall and tile discharge (Figure 4-1). A field near Ottawa (Leclerc Field) which is 14 ha in area and has sandy loam soil was monitored, as was a 5 ha field near Napanee, which has a heavy clay loam soil overlying limestone bedrock (Figures 4-2 and 4-3).

The Leclerc field depicted in Figure 4-2 has tiles spaced at intervals of 16.8 metres. A Stevens type F recorder was used to monitor the water level in a collection tank with a compound V-notch weir. A chart recording, tipping bucket rain gauge was located within 500 m of the field. Water levels over the weir and rainfall rates were recorded continuously from May 1985 to November 1985 and again from May to December 1986.

Instrumentation on the Napanee field (Figure 4-4) included a collection tank with a compound V-notch weir at the tile outlet. Water levels over the weir were recorded continuously from April to December 1986 with the use of a Stevens A-71 chart recorder at a 1:1 recording ratio and a speed of 6.0 cm/day. Rainfall volumes and rates were also recorded with a tipping bucket rain gauge and a continuous strip chart recorder (Weather Measure Corporation Model P522). Five observation wells consisting of 100 mm ABS pipe, sleeved in filter fabric were installed to allow periodic measurements of watertable elevation. Summaries of the larger rainfall events recorded on the two test fields are presented in Tables 4.1 and 4.2.

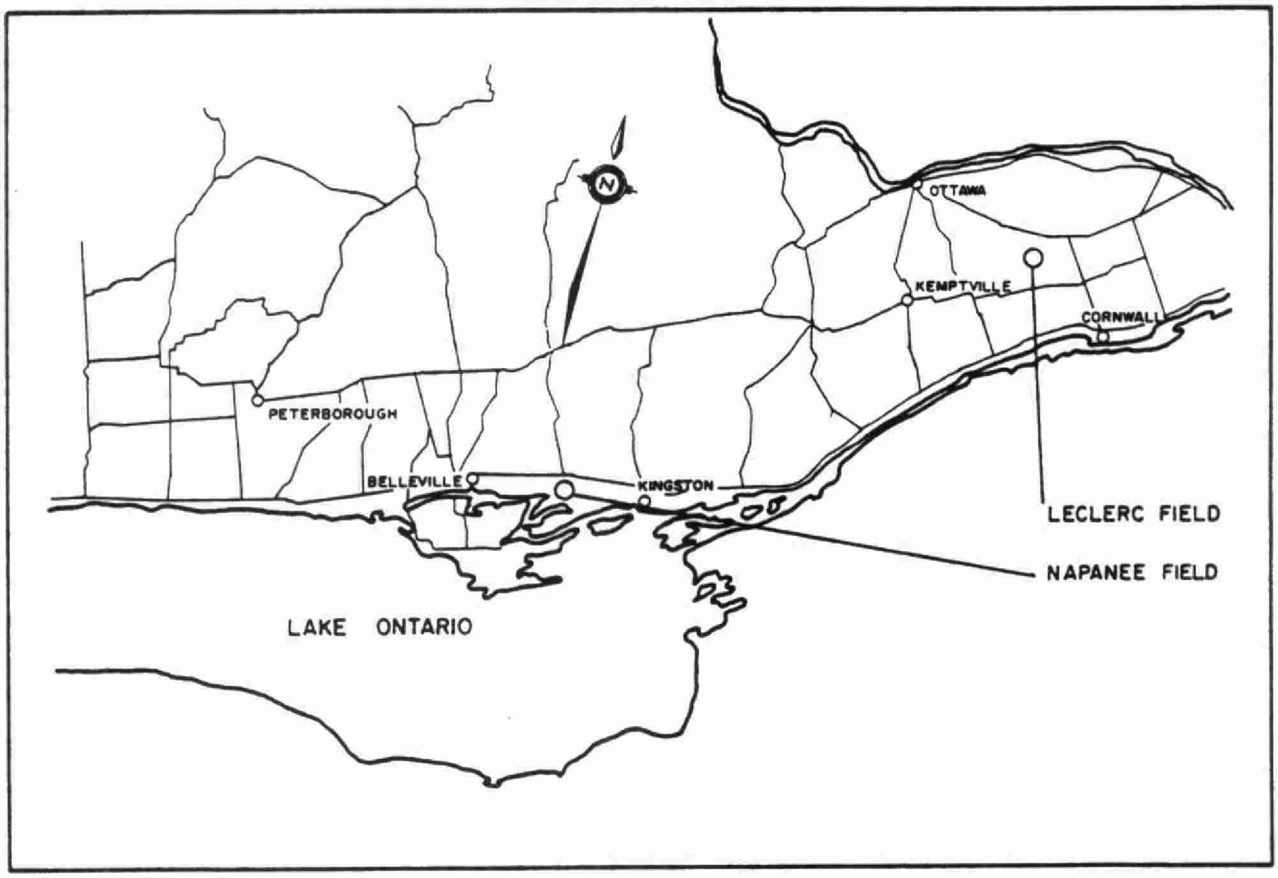
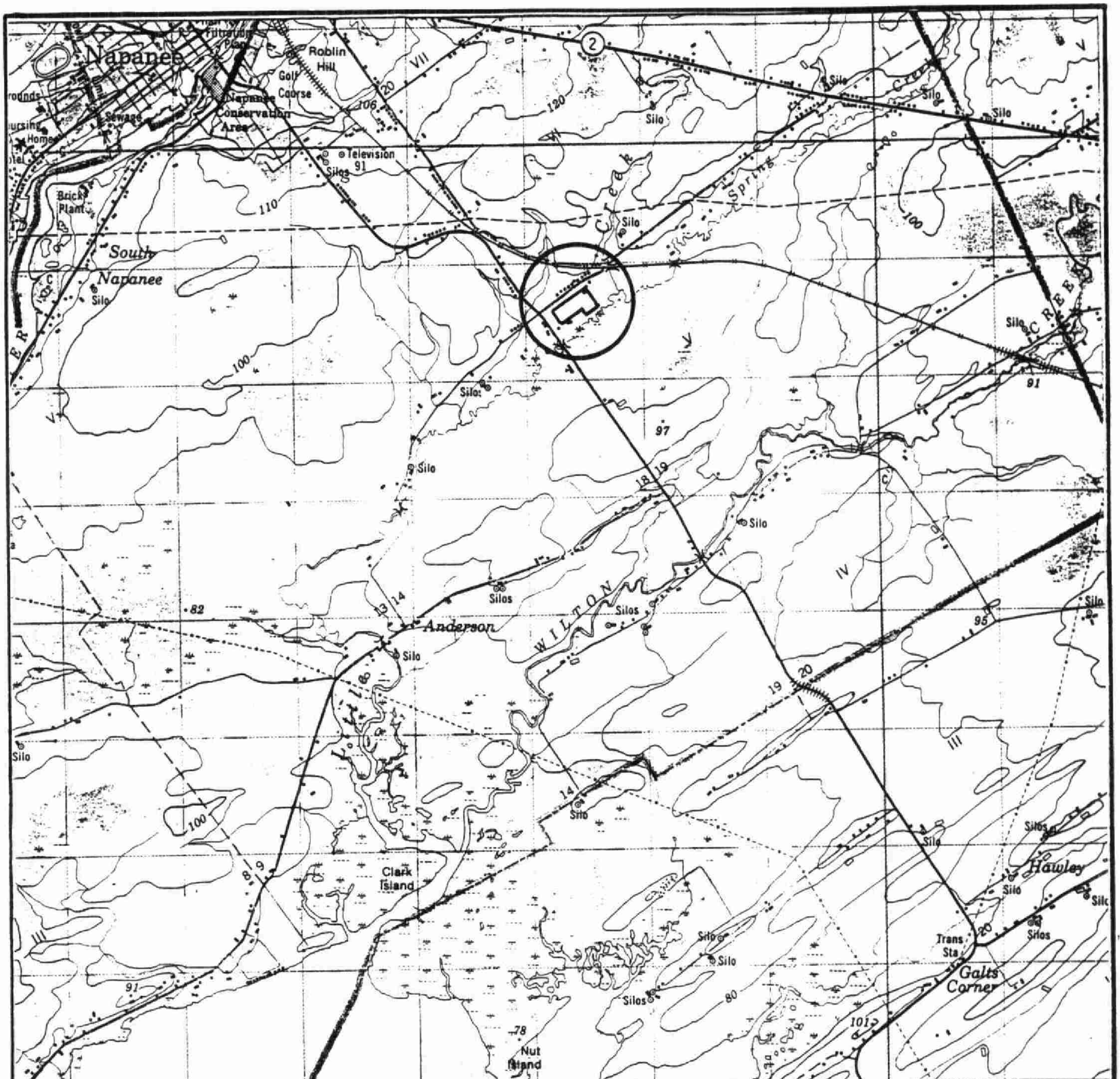
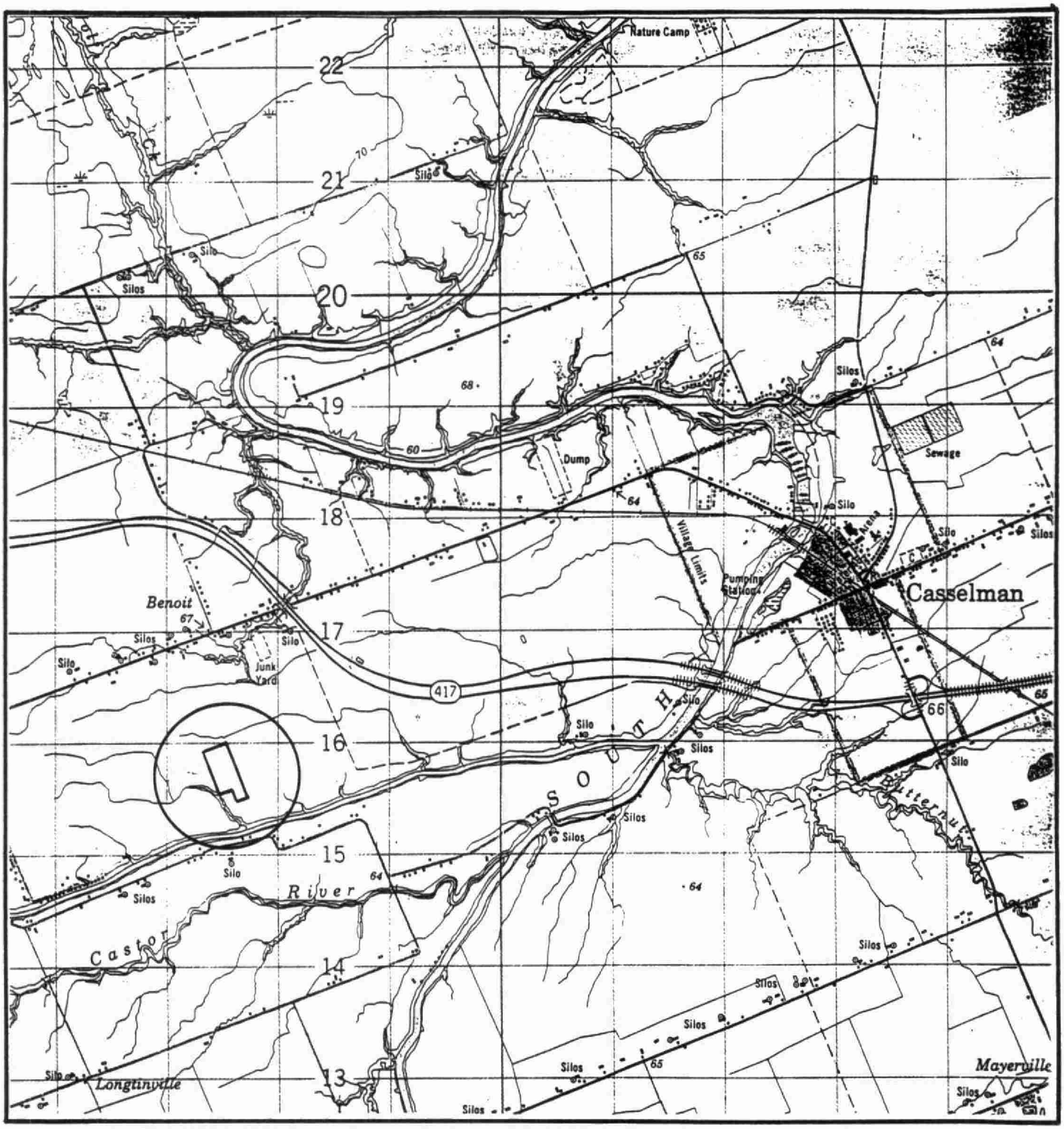


Figure 4-1 Locations of instrumented fields



SCALE 1:50,000

Figure 4-2 Location Plan - Napanee field



SCALE 1:50,000

Figure 4-3 Location Plan - Leclerc field

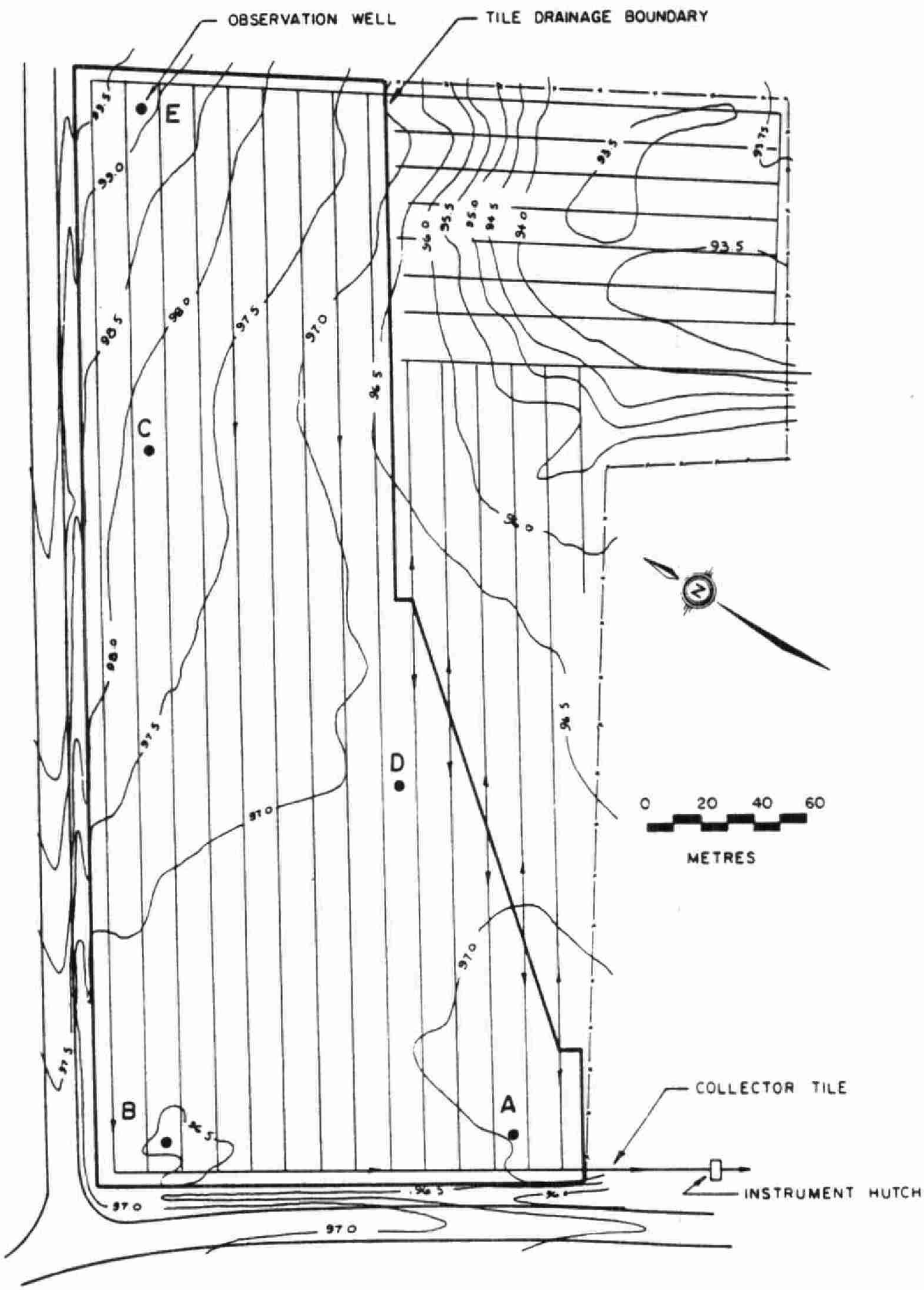


Figure 4-4 The Napanee field

Table 4.1 **Summary of storm events - Napanee Field**

Date (1986)	Rainfall (mm)	Tile Runoff (mm)	Peak Tile Flow (m^3/s)	Surface Flow (simulated) (mm)
Apr 15-21	23.4	13.4	0.0038	0
May 19-23	89.8	31.7	0.0117	18.2
June 11-16	71.4	28.7	0.0124	3.5
Aug 15-18	19.0	0.6	0.0003	0
Sept 10-16	90.4	35.8	0.0122	13.2
Sept 22-28*	36.4	22.8	0.0122	3.5
Sept 29-06*	56.8	36.1	0.0118	0
Oct 12-16*	22.0	11.2	0.0063	0

* simulated

Table 4.2 **Summary of storm events - Leclerc Field**

Date (1986)	Rainfall (mm)	Tile Runoff (mm)	Peak Tile Flow (m^3/s)	Surface Flow (simulated) (mm)
May 19-24	45.4	7.1	0.0056	0
July 03-08	40.9	2.5	0.0029	0
Sept 11-19*	49.1	14.7	0.0091	0
Sept 23-26	12.2	2.7	0.0044	0
Sept 29-07*	50.0	22.5	0.0119	0
Oct 12-18*	19.3	14.4	0.0102	0
Oct 26-30	26.3	6.4	0.0075	0

* Verification events for simulation model (Section 5.6)

4.2 Field Studies Program - Napanee Field

The Napanee field (Figure 4-4) was also the subject of a comprehensive field studies program for the determination of the field's physical properties. The topographic survey of the field shows it to be gently sloped in a north-south direction with the slopes ranging from 0.0008 to 0.001 m/m. The limestone bedrock is not at a constant elevation under the field, but varies in depth from approximately 0.6 m along the northern edge to approximately 2.0 metres at the southern end. The soil is a Lansdowne clay (Gillespie et al. 1963) overlying an Ordovician limestone. The tiles are spaced at 12.2 metres and define a subsurface drainage area of 5.04 ha.

Soil moisture measurements were taken throughout the summer months to ascertain the initial soil moisture content of the field prior to rainfall events. Bulk density measurements were taken and an extensive testing program was conducted to determine the hydraulic conductivity and drainable porosity at various depths and locations throughout the field. Additional detail on the field measurement techniques and analyses may be found in Whyte (1987).

4.2.1 Saturated Hydraulic Conductivity

Techniques to assess the saturated hydraulic conductivity of the Napanee soil included:

i) laboratory measurements using a falling head permeameter,

ii) the field determination of K_s using the Guelph permeameter (in the presence of a low groundwater table).

iii) the field determination of K_s using the auger hole method (in the presence of a high groundwater table), and

iv) the determination of a field effective value of K_s using Hooghoudt's equation.

Both the laboratory measurements and measurements determined using the Guelph permeameter were not deemed to be satisfactory. The laboratory technique involved reforming the soil sample and as such the macro structure of the soil which might more properly determine the field effective conductivity was destroyed.

The Guelph permeameter yielded results which were either undefined (negative conductivity), or wildly scattered. The primary difficulty appeared to be the smearing of the walls of the test holes bored for the test. The smear layer, particularly during moist soil conditions, provided an effective hydraulic barrier to the soil profile (Whyte, 1987).

The auger hole method was used to obtain measurements of saturated hydraulic conductivity during the spring and fall periods when the water table was near the surface. Tests were conducted (Whyte 1987) using observation wells A, C and D, and four 60 mm diameter holes bored to a depth of 0.9 m. To reduce the effect of smearing that occurred on the boring of test holes, the holes were not used for testing until the water table had risen and fallen over the hole depth, or until the hole had been pumped out and refilled several times. Test data was reduced using a formula developed by Kirkham and von Bavel (1948) for the case where an impermeable layer coincides with the bottom of the bored hole. A minimum of two tests were performed on each of the seven test holes and additionally two depth ranges were considered for test holes near observation well A. The results are displayed in Table 4.3. As may be seen from the table, hydraulic conductivity does decrease with depth. With depth the soil structure becomes more dense with fewer macro pores and organic material.

Table 4.3 Summary of auger hole test results

Area	**Depth** (m)	**Hydraulic Conductivity** (m/day)
A	0.0 - 0.5	0.18
	0.5 - 1.0	0.01
C	0.0 - 0.5	0.27
D	0.5 - 1.0	0.02

Hooghoudt's equation was also used to determine an integrated field effective value of saturated hydraulic conductivity from the tile drainage system performance. Whyte (1987) shows a plot of observed drainage rate versus water table height above the drain axis (Figure 4-5). Also depicted on the figure is the drainage rate as determined from Hooghoudt's equation for various values of K_s. As may be seen from the figure, the observed data may be represented by a range of values for hydraulic conductivity (from .10 to .30 m/day) depending on the location of the water table. The selected integrated value of 0.3 m/day gives reasonable results over the range with a more exacting match for cases where the water table is at the surface (equilibrium flow conditions).

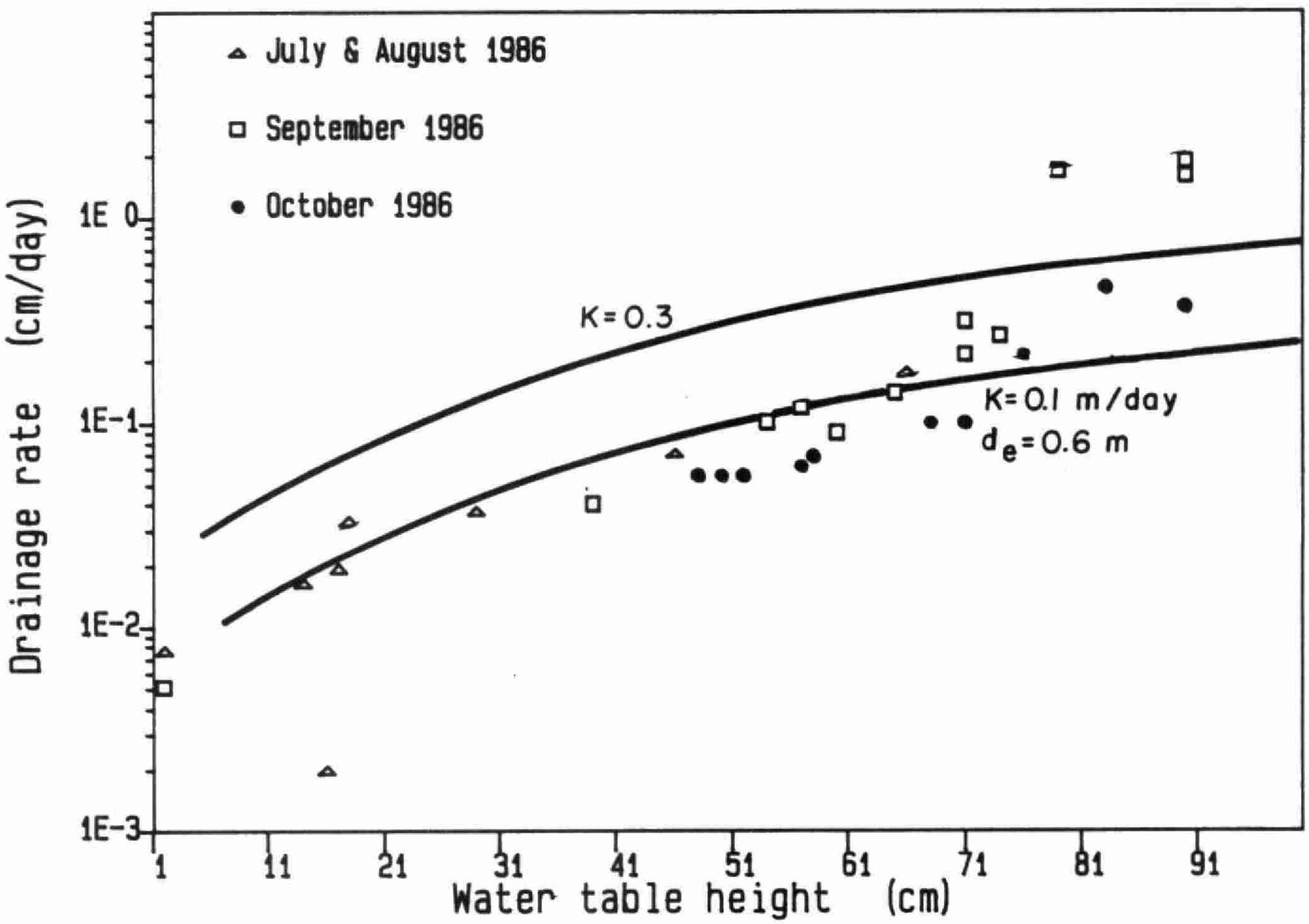


Figure 4-5 Drainage rate for varying water table heights on test field

4.2.2 Drainable Porosity

The average drainable porosity represents the specific yield or maximum water available through gravity drainage on a volume of water per volume of soil basis for the soil layer above the tile axis. This figure represents the difference between the saturated moisture content and the field capacity of the soil. The average drainable porosity was determined directly from the field drainage data following a method outlined by Taylor (1960) which involves integration of the recession limb of the tile discharge hydrograph and relating this volume to the drop in the groundwater table over the same time period (Figure 4-6). This field technique tends to integrate variations in drainable porosity which could come about due to minor differences in soil type over the field; also included would be the effects of macro pores on the porosity and the effects of layered soil. These insitu variations would not be accounted for through use of laboratory procedures on small samples. Average drainable porosity for the Napanee clay was determined to be in the order of 2 percent and did not appear to be dependent on water table depth over the ranges considered (0 - 0.7 m) (Figure 4-7).

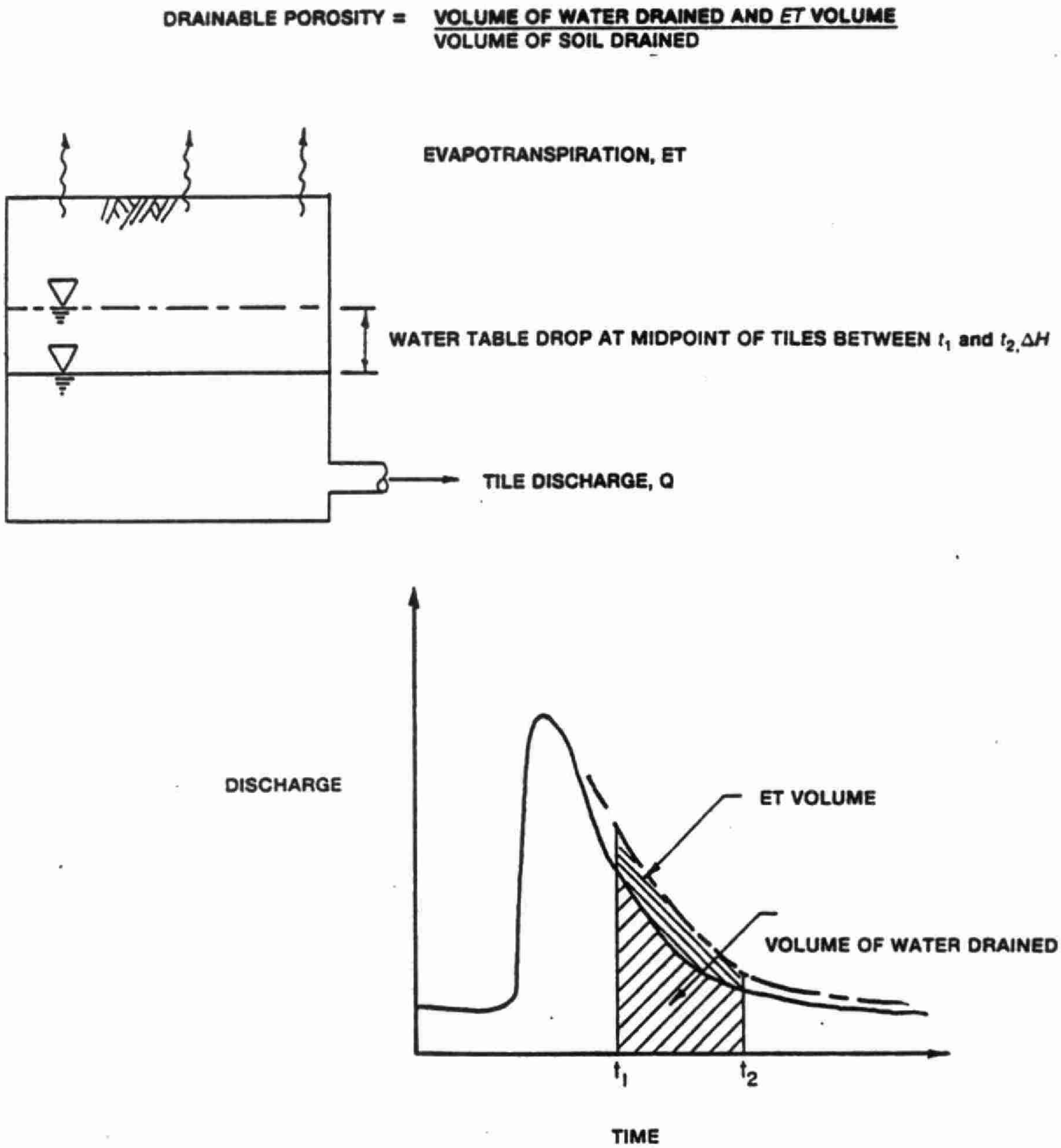


Figure 4-6 Determination of drainable porosity

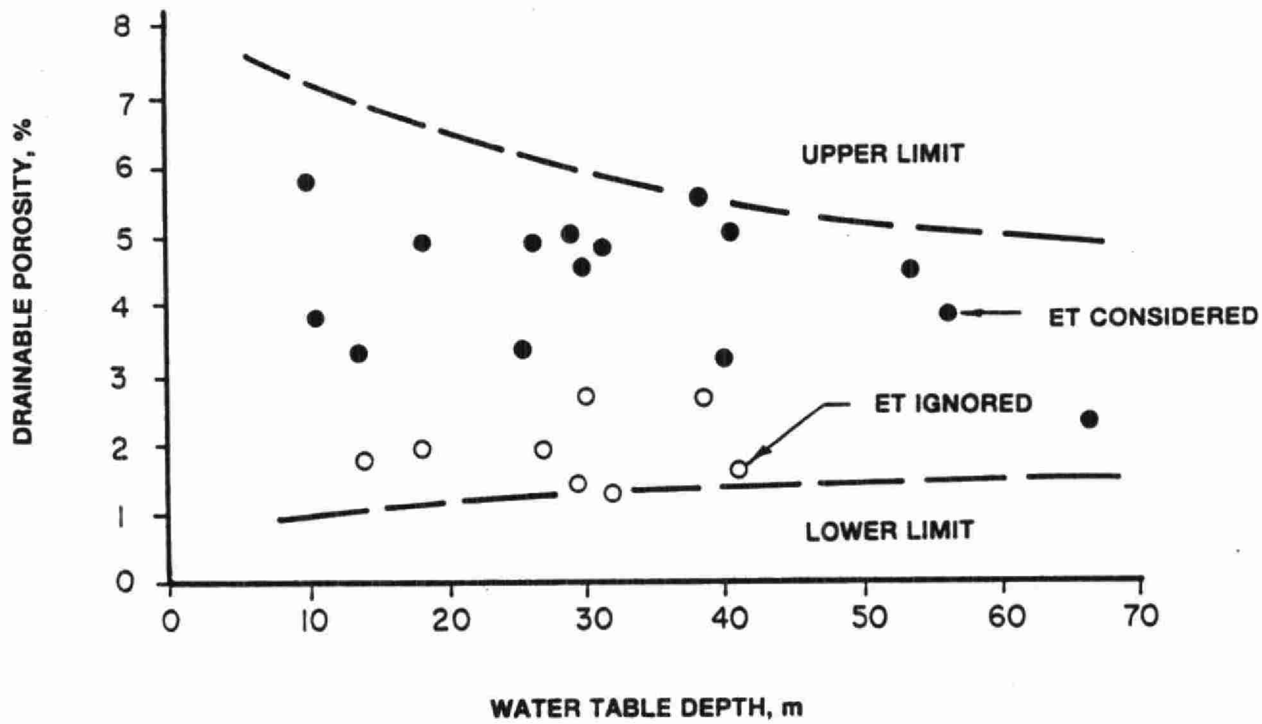


Figure 4-7 Drainable porosity as a function of depth of water table

5.0 TILED FIELD SIMULATION MODEL

5.1 Introduction

TILE is a physically-based model designed to simulate the hydrologic responses of an agricultural field subjected to tile drainage. Processes modelled are infiltration, filling depression storage, percolation of infiltrated water into the root zone and the lower zone, groundwater flow and evapotranspiration from the soil surface and lower zone.

The modelling of the groundwater table and tile discharge is treated as a linear reservoir described by the hydraulic conductivity of the soil and a constant drainable porosity. Physical processes are modelled with relatively simple algorithms which the authors believe to be compatible with the levels of accuracy possible in measuring the physical characteristics and parameters of the fields being simulated.

5.2 Modelling Considerations

One of the primary considerations during the development of the model was the desire to maintain a balance between the complexity in describing the physical processes and the accuracies possible in measuring the physical characteristics and parameters of the prototype fields. Accordingly, the following considerations were deemed important.

- The model should be modular and decomposed into physically separable components.

- The model algorithms should be as simple as possible, with additional complexities introduced only where required and as

justified by field measurements.

- The model should contain a minimum number of parameters requiring calibration.

- Where possible, parameters should be physically based (i.e. measurable independent of the model) and determinable with a minimum of field effort.

- The model should be capable of simulating short (hourly) time steps for accurate assessment of surface and subsurface hydrographs.

- The model should be robust and capable of accurate simulation for a wide range of soil types and tile configurations.

5.3 Overview of Physical Processes

TILE, a physically-based deterministic model, simulates on an hourly basis, the hydrological responses of an agricultural field subjected to tile drainage. Figure 5-1 illustrates the systematically tile drained field which TILE is capable of modelling. Also illustrated is the method of defining an equivalent tile lateral length for situations where the systematic drainage has varying tile lengths. The model is not suited for accurately modelling random or dendritic type drainage schemes.

As in any conceptual model replicating a hydrologic system, the natural system may be represented by storage elements linked with transmission elements. Figure 5-2 illustrates this representation of the real system by the model.

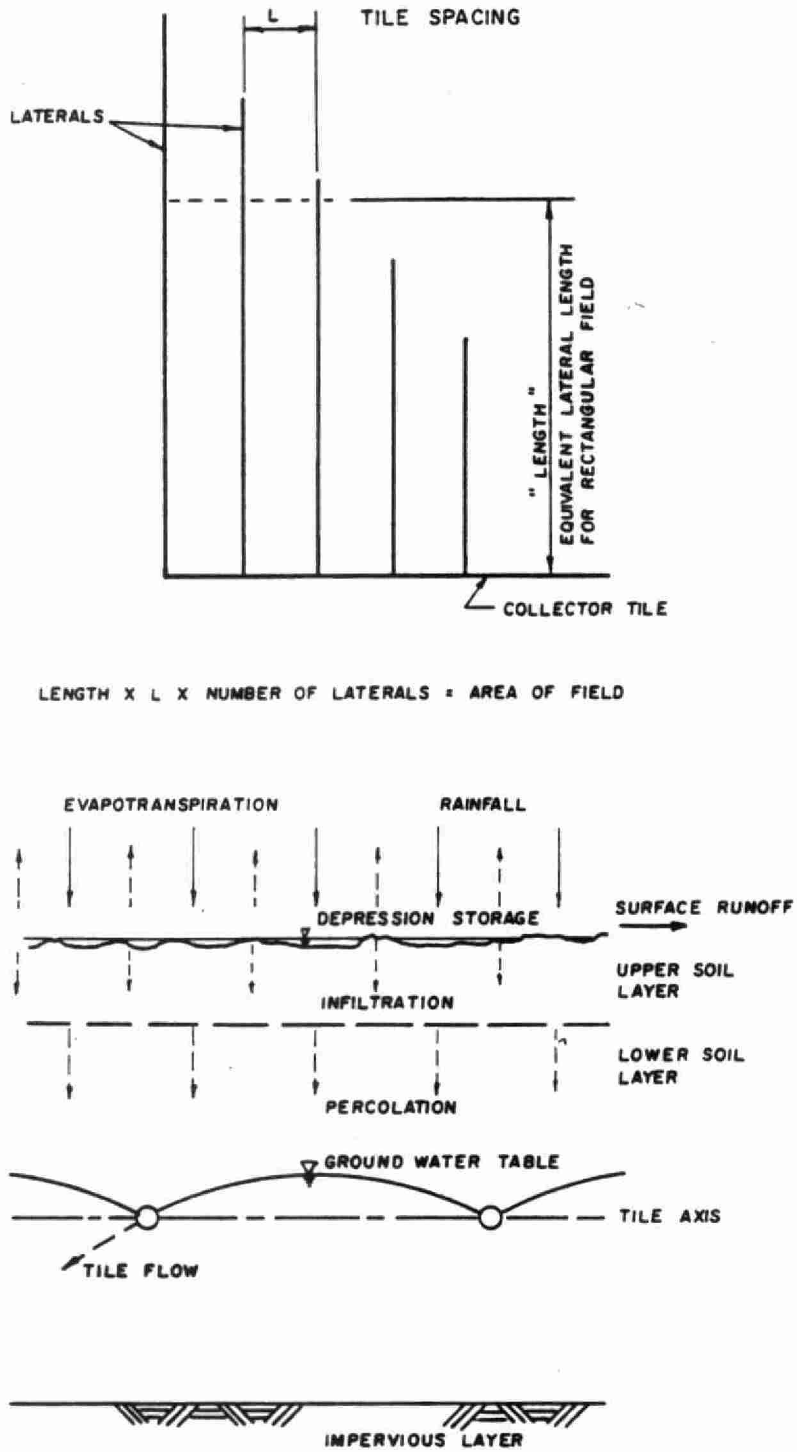


Figure 5-1 The physical system - a systematically tile drained field

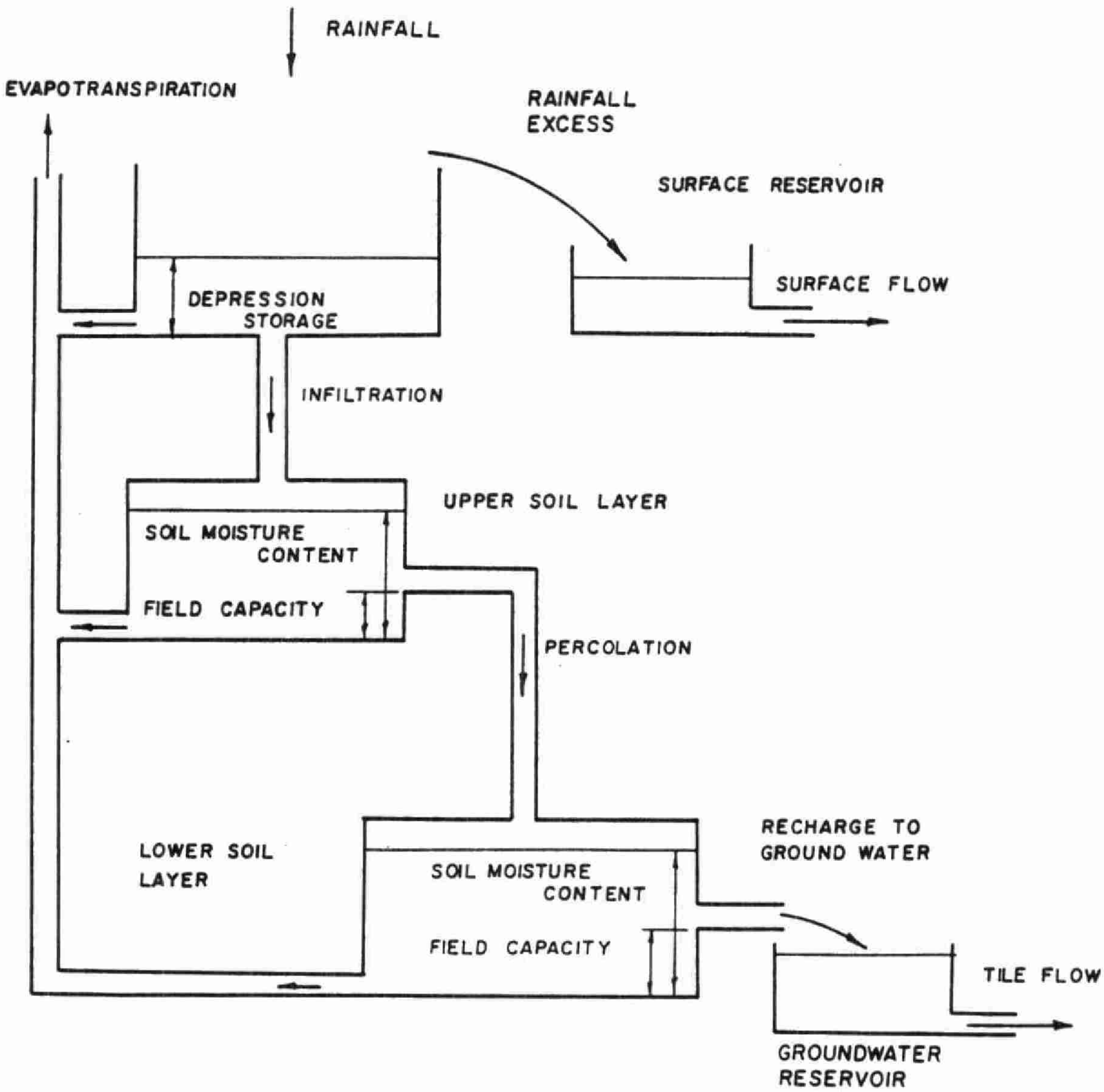


Figure 5-2 Conceptual representation of physical system

The storage elements include:

i) depression storage on the surface of the field,

ii) temporary surface storage to provide the driving head for surface runoff,

iii) both upper zone and lower zone soil moisture storage, and

iv) a groundwater reservoir represented by the elevation of the groundwater table.

Transmission elements include:

i) routing of surface flow to the edge of the field,

ii) infiltration to the upper soil moisture zone,

iii) evapotranspiration from soil moisture and groundwater,

iv) percolation from the upper zone to the lower zone,

v) recharge to the groundwater reservoir, and

vi) discharge from the groundwater reservoir to the tile drainage system.

5.4 Model Components*

5.4.1 Surface Submodel

Rainfall arriving at the field surface first enters a depression storage reservoir which has a maximum depth (depression storage capacity) depending on the evenness of the field or its present state (ploughed or harrowed).

The volume in depression storage depends on the rainfall, the depression storage capacity and three transfer functions: infiltration, evapotranspiration and spill to the surface runoff reservoir. From the depression storage reservoir, evaporation, infiltration and rainfall excess are satisfied in that order.

---

* This section presents a brief overview of the algorithms used in the Tile simulation model. Readers requiring additional detail are referred to the program notes developed for the model. (Paine et al. 1987).

$$[1] \quad D_t = D_{t-\Delta t} + (r-f-e)\ \Delta t \text{ if } D_t \leq Dmax \text{ (else } D_t = Dmax)$$

$$[2] \quad i = r-f-e + D_{t-\Delta t} - D_t)/\Delta t$$

where D_t is the depression storage depth at time t, r is the rainfall intensity, f is the infiltration rate, e is the evaporation rate, i is the rate of rainfall excess, and Δt is the time interval.

Rainfall excess is routed through two linear reservoirs in series to develop the surface flow hydrograph.

$$[3] \quad qs_t = 2e^{-t/k}\ qs_{t-1} - e^{-2t/k}\ qs_{t-2} + (t/k)^2\ e^{-t/k}.i_t$$

where qs_t = surface runoff per unit area.

The recession constant k is a function of the travel time of the excess water on the agricultural field.

$$[4] \quad k = .6T_p = .6(4.3 \times 10^{-4})\ (L/s^{.5})^{.748}$$

The maximum rate at which the soil surface can accept the moisture input (infiltration capacity) is based on the existing soil moisture content of the root zone according to an equation suggested by Holtan (1961).

$$[5] \quad f_p = a.(SMCU_m - SMCU)^{1.4} + f_c$$

where f_p is the infiltration capacity (mm/h), a is an index of surface connected porosity which is a function of surface conditions and the density of plant roots, $SMCU_m$ is the saturated soil moisture content in the upper zone (mm), SMCU is the existing soil moisture content in the upper zone, and f_c is the ultimate infiltration capacity (mm/h).

Actual infiltration f depends on the rainfall rate and the infiltration capacity

[6] $f = f_p$ for $r \geq f_p$ else $f = r$

5.4.2 Soil moisture submodel

Soil moisture storage is considered in two distinct zones, an upper zone or root zone typically 200-400 mm in thickness and a lower zone between the upper zone and the tile axis. Soil moisture storage in the upper zone is treated independently of moisture storage in the lower zone unless the groundwater table enters the upper zone (lower zone saturated). Prior to any percolation into the lower zone, the field capacity of the upper zone must be filled. With the field capacity full, percolation into the lower zone is related to the soil moisture in the upper zone;

[7] $$p = \frac{(\theta_u - \theta_{fu})}{(\theta_s - \theta_{fu})} f_c$$

where p is the percolation rate to the lower zone (mm/h), θ_u is the upper zone moisture content expressed as a decimal fraction of 1.0, θ_{fu} is the upper zone moisture content at field capacity, and θ_s is the saturated moisture content of upper zone.

Soil moisture content in the upper zone is increased by the infiltration previously computed but is decreased by the percolation. The upper soil zone may become saturated in spite of unsaturated conditions in the lower zone. If the water table enters the upper zone, the soil moisture is calculated as a function of the water table depth above the lower boundary of the upper zone.

Water percolating into the lower zone must first satisfy the field

capacity of this zone prior to releasing water to the drain tiles. Once field capacity has been reached, excess water is added to the groundwater table and subsequently released to the drain tile. To avoid double accounting for the zone or zones containing the groundwater table, soil moisture is calculated directly from the position of the groundwater table.

Water which percolates from the upper zone is not lagged before appearing in the lower zone; it is assumed to appear instantly at the tile or water table where it becomes available for recharge to the tiles. The lag in the system as a result of the velocity of the wetting front must be accounted for in the storage and percolation from the upper zone.

5.4.3 Groundwater table and tile flow submodel

Recharge to the groundwater table and groundwater discharge are modelled according to a linearized form of the transient flow equations, a solution to which was proposed by DeZeeuw and Hellinga (1958) who combined Hooghoudt's steady state equation (Hooghoudt 1940) with an expression for continuity.

Tile flow per unit area q and groundwater storage per unit area S are related through the equation of continuity for the control volume.

[8] $R - q = dS/dt$

In these equations R represents the water recharging the groundwater table. Depending on the location of the groundwater table in the soil profile this recharge rate may be the percolation rate, the infiltration rate or when the water table is at the soil surface, the drainage coefficient (the equilibrium flow).

At any time, groundwater storage and water table height m are related by

[9] $S = C \mu m$

where C is a constant less than or equal to unity to account for changes in the water table shape with time, μ is the drainable porosity of the soil and m represents the water table height at time t.

For a constant drainable porosity

[10] $R - q = C \mu \, dm/dt$

If Hooghoudt's steady-state solution is assumed to apply at any instant during unsteady conditions, then a second expression relating q and m is obtained.

[11] $q = \frac{8K_s dm}{L^2} + \frac{4K_s m^2}{L^2}$

where K_s is the saturated hydraulic conductivity, L is the drain spacing, m is the height of water table above the tile axis at the midpoint between the tiles, and d is the equivalent depth to the impervious layer (a modification of the actual depth depending on the drain spacing and diameter of the tiles (Moody 1966).

The expression relating q to m given by [11] is non-linear; simplified solution procedures can be employed if it is linearized. A common approach is to ignore the second term on the right side on the basis that m << 2d, i.e.

[12] $q = 4 K_s m (2d + m)/L^2 \approx 8 K_s dm/L^2$

The effect of this linearization is to ignore the flow contribution due to groundwater flow above the tile axis ($4 K_s m^2/L^2$). However with this

simplification, the difference between the solutions to the linearized and non-linear expressions becomes a maximum when the water table is at the surface ($m = M$), a common design condition.

An alternative linearized expression is achieved by replacing m^2 in the second term by mM so that there is agreement between the linear and non-linear forms when the water table is at the surface and a maximum difference when the water table is at the tile elevation [13].

In any event, the differences in these linearizations are small compared with the uncertainty in estimation of hydraulic conductivity.

[13] $q \approx 4\ K_s\ m\ (2d + M)/L^2$

or

[14] $m = q\ L^2/4\ K_s\ (2d + M)$

With this linear relation between outflow and storage, the system is analogous to a linear reservoir and after substituting [13] in [10] the solution expressed in recursive form becomes,

[15] $q_t = q_{t-1}\ e^{-\Delta t/T} + R_t\ (1-e^{-\Delta t/T})$

where $T = L^2\ C\ \mu/(8\ K_s\ d + 4\ K_s\ M)$

5.4.4 Evapotranspiration Submodel

Thornthwaite's equation (Thornthwaite and Holzman 1942) is used to calculate the potential evapotranspiration from the depression storage and the soil surface. The evaporation requirements are met at the beginning of each time step from the depression storage, the upper soil zone and the lower soil zone in order.

Evaporation from the depression storage takes place at the maximum potential evapotranspiration rate (water unlimited). Evapotranspiration from the soil layers takes place at the maximum potential rate (E_p) as long as the moisture content is greater than 60 percent of the saturated value. For lower values of soil moisture the actual evapotranspiration rate E_a is linearly related to the soil moisture content θ [16].

$$[16] \quad E_a = E_p \times \frac{\theta}{\theta_s} \times \frac{1}{0.6} \qquad \text{for } \frac{\theta}{\theta_s} < 0.6$$

5.5 Brief Description of Input and Output

Input for the TILE programs is contained in 3 files:

i) a field characteristics file which contains the physical characteristics and soil parameters of the tile-drained field and the observed hydrograph,

ii) a rainfall file which contains the rainfall hydrograph in hourly increments, and

iii) a temperature file which contains mean monthly temperature data and daily temperatures during the period to be simulated.

Figure 5-3 displays samples of these 3 files for a particular field and event. Output for the model is displayed in Figures 5-4 to 5-6.

```
CONTROL     2 1 1 0 0 1
PLOT        1 1      .000
FIELD       100.0  12.2    14     295.0  .0070  .005.57 400.
SOIL         .300   1.5    1.00  .020    2.
UPPER        .23   .250   300.0   .10  14.0
LOWER        .450  .450   700.0     7
```

FIELD FILE

```
BLANK IDENTIFIER LINE
            12 30
ADJ           .81  .82 1.02 1.13 1.27 1.29 1.30 1.29 1.04  .95  .80  .76
MEAN MTH  -14.7 -1.5 -.20  1.6 12.3 17.6 20.8 18.6 13.7  5.5  1.7 -3.8
999    198604
9.98.87.67.65.54.37.76.04.02.30.32.25.53.38.78.913.13.11.9.73.60.15.37.3
15.16.17.16.13.11.
BLANK IDENTIFIER LINE
            12 31
ADJ           .81  .82 1.02 1.13 1.27 1.29 1.30 1.29 1.04  .95  .80  .76
MEAN MTH  -14.7 -1.5 -.20  1.6 12.3 17.6 20.8 18.6 13.7  5.5  1.7 -3.8
999    198605
7.55.52.93.312.11.14.9.412.9.816.13.15.13.15.13.14.15.12.11.11.13.12.11.
16.17.17.21.21.18.16.
```

TEMPERATURE FILE

```
RAIN        MAY0101 1.0    31
999    860501   0    0    0    0    0    0    0    0    0    0    0    0
                0  1.4  1.4    0    0    0    0    0    0    0    0    0
999    860502   0    0    0    0    0    0    0    0    0    0    0    0
                0    0    0    0    0    0    0    0    0    0    0    0
999    860503   0    0    0    0    0    0    0    0    0    0    0    0
                0    0    0    0    0    0    0    0    0    0    0    0
999    860504   0    0    0    0    0    0    0    0    0    0    0    0
                0    0    0    0    0    0    0    0    0    0    0    0
999    860505   0    0    0    0    0    0    0    0    0    0    0    0
                0    0    0    0    0    0    0    0    0    0    0    0
999    860506   0    0    0  0.4  1.6  0.6  0.2    0    0    0    0    0
                0    0    0    0    0    0    0    0    0    0    0    0
```

RAIN FILE

Figure 5-3 Input data for TILE program

DIA. OF DRAINS		=	100.0
EFFECTIVE RADIUS		=	.0050
SPACING OF DRAINS		=	12.2
NO. OF ROWS		=	14
LENGTH OF DRAINS		=	295.
SURFACE SLOPE		=	.00700
SURFACE FLOW LENGTH		=	400.00000
EVAP CONSTANT		=	.57000
COEFF. OF PERMEABILITY		=	.30
DEPTH OF IMP. LAYER FROM DRAIN AXIS		=	1.500
AVERAGE FLUX COEFFICIENT		=	1.000
DRAINABLE POROSITY		=	.020
DEPRESSION STORAGE CAPACITY		=	2.0
SURFACE N=2	ALPHA	=	6.85656
	PHI1	=	.50755
	PHI2	=	-.06440
	THETA	=	.55685
GROUND WATER	ALPHA	=	.03806
	COEFFICIENT	=	.96266
EQUILIBRIUM FLOW		=	.761

DATA FOR UPPER SOIL LAYER

INITIAL SOIL MOISTURE CONTENT	=	.230
FIELD CAPACITY	=	.25
COEFFICIENT A	=	.10
CONSTANT INFILTRATION FC	=	14.00
DEPTH OF THE LAYER	=	300.0

DATA FOR LOWER SOIL LAYER

INITIAL SOIL MOISTURE CONTENT	=	.45
FIELD CAPACITY	=	.45
DEPTH OF THE LAYER	=	700.0
HE EFFECTIVE DEPTH	=	.63

```
**********************************************
*                                            *
*      S U M M A R Y     O U T P U T         *
*                                            *
**********************************************
```

		VOLUME (MM)
GAIN:		
PRECIPITATION	=	41.00
LOSS:		
EVAPOTRANSPIRATION	=	24.20
SURFACE RUNOFF	=	.00
TILE DRAINAGE	=	21.56
BALANCE (GAIN-LOSS):		-4.77
FINAL SOIL MOISTURE CONTENT	=	379.23
INITIAL SOIL MOISTURE CONTENT	=	384.00
CHANGE IN STORAGE :		-4.77
SIMULATED TILE FLOW	=	21.56
OBSERVED TILE FLOW	=	18.94
SEW 30 (CM-DAYS)	=	.00

Figure 5-4 Output - echo check and summary

```
*****************************************
*                                       *
*   D E T A I L      O U T P U T        *
*                                       *
*****************************************
```

DATE	TIME (HR)	RAIN (MM)	SMC1 (MM)	SMC2 (MM)	Z (MM)	SURFACE FLOW (CMS)	SIMULATED FLOW (CMS)	OBSERVED FLOW (CMS)
SEP29	1.	0.	48.	119.	0.	.00000	.00000	.00000
	2.	3.	51.	119.	0.	.00000	.00000	.00000
	3.	2.	53.	119.	1.	.00000	.00004	.00000
	4.	0.	51.	120.	15.	.00000	.00076	.00000
	5.	0.	51.	120.	13.	.00000	.00069	.00003
	6.	0.	51.	120.	12.	.00000	.00063	.00007
	7.	0.	51.	120.	11.	.00000	.00057	.00019
	8.	0.	51.	120.	10.	.00000	.00051	.00014
	9.	0.	51.	120.	9.	.00000	.00045	.00017
	10.	0.	51.	120.	7.	.00000	.00039	.00019
	11.	0.	51.	120.	6.	.00000	.00033	.00028
	12.	2.	53.	120.	6.	.00000	.00032	.00029
	13.	0.	51.	121.	24.	.00000	.00123	.00036
	14.	0.	51.	121.	22.	.00000	.00116	.00042
	15.	0.	51.	121.	21.	.00000	.00110	.00051
	16.	0.	51.	121.	20.	.00000	.00103	.00059
	17.	0.	51.	121.	19.	.00000	.00096	.00085
	18.	0.	51.	121.	17.	.00000	.00089	.00094
	19.	0.	51.	121.	16.	.00000	.00083	.00099
	20.	0.	51.	120.	15.	.00000	.00077	.00104
	21.	0.	51.	120.	14.	.00000	.00070	.00109
	22.	0.	51.	120.	12.	.00000	.00064	.00112
	23.	1.	52.	120.	12.	.00000	.00063	.00115
SEP30	0.	1.	51.	121.	23.	.00000	.00117	.00119
	1.	1.	51.	122.	29.	.00000	.00149	.00133
	2.	3.	54.	122.	33.	.00000	.00170	.00152
	3.	13.	63.	126.	73.	.00000	.00379	.00218
	4.	7.	53.	143.	240.	.00000	.01243	.00999
	5.	0.	51.	144.	253.	.00000	.01314	.01170
	6.	0.	51.	144.	249.	.00000	.01292	.01192
	7.	0.	51.	143.	245.	.00000	.01271	.01192
	8.	0.	51.	143.	241.	.00000	.01249	.01192
	9.	0.	51.	143.	237.	.00000	.01228	.01192
	10.	0.	51.	142.	233.	.00000	.01207	.01192

Figure 5-5 Detailed output

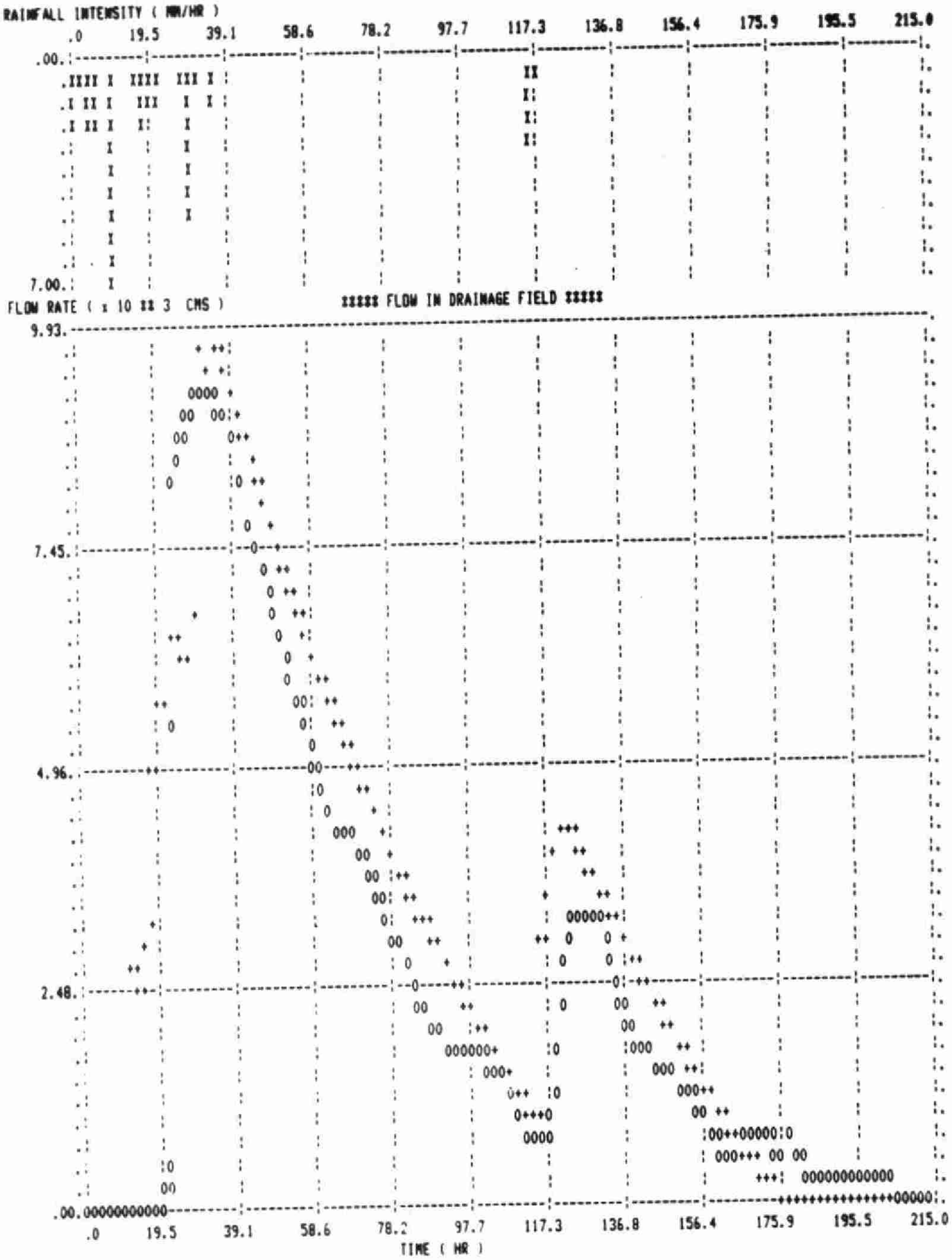


Figure 5-6 Tile flow hydrograph

Input data is echoed, a summary water balance is presented and the discharge hydrograph and groundwater elevation with time are displayed as plots. Additional detail on moisture contents, drain discharge and groundwater elevations is available with each time step as an option to assist in debugging or program development.

5.6 Model Calibration and Verification

Using information from the field studies program and typical ranges of physical parameters from the literature, the model was calibrated on approximately one half of the available events from each field and verified on the remaining events [1]. Calibration concentrated on matching the observed tile runoff volume, the observed peak discharge and on matching the time to peak. Water table observations were not taken on the Leclerc field and were not performed continuously for the Napanee field; consequently these observations were not considered in the model calibration.

Reasonably satisfactory results were obtained for the fields for both the volume of tile discharge and the peak tile flow (Figure 5-7). Agreement between simulated and observed tile flow for the Leclerc field with its rapidly draining sandy loam was somewhat better than that for the Napanee field. The recession limb of the tile flow hydrograph for the Napanee field was difficult to fit, and suggests that the approximation of the groundwater discharge and storage relationship to a linear reservoir may require modifications. Figures 5-8 and 5-9 display the modelled and observed tile flows for a selected event for each field.

Field characteristics and calibration values of parameters are given in Tables 5.1 and 5.2.

1. Refer to Table 4.1 & 4.2

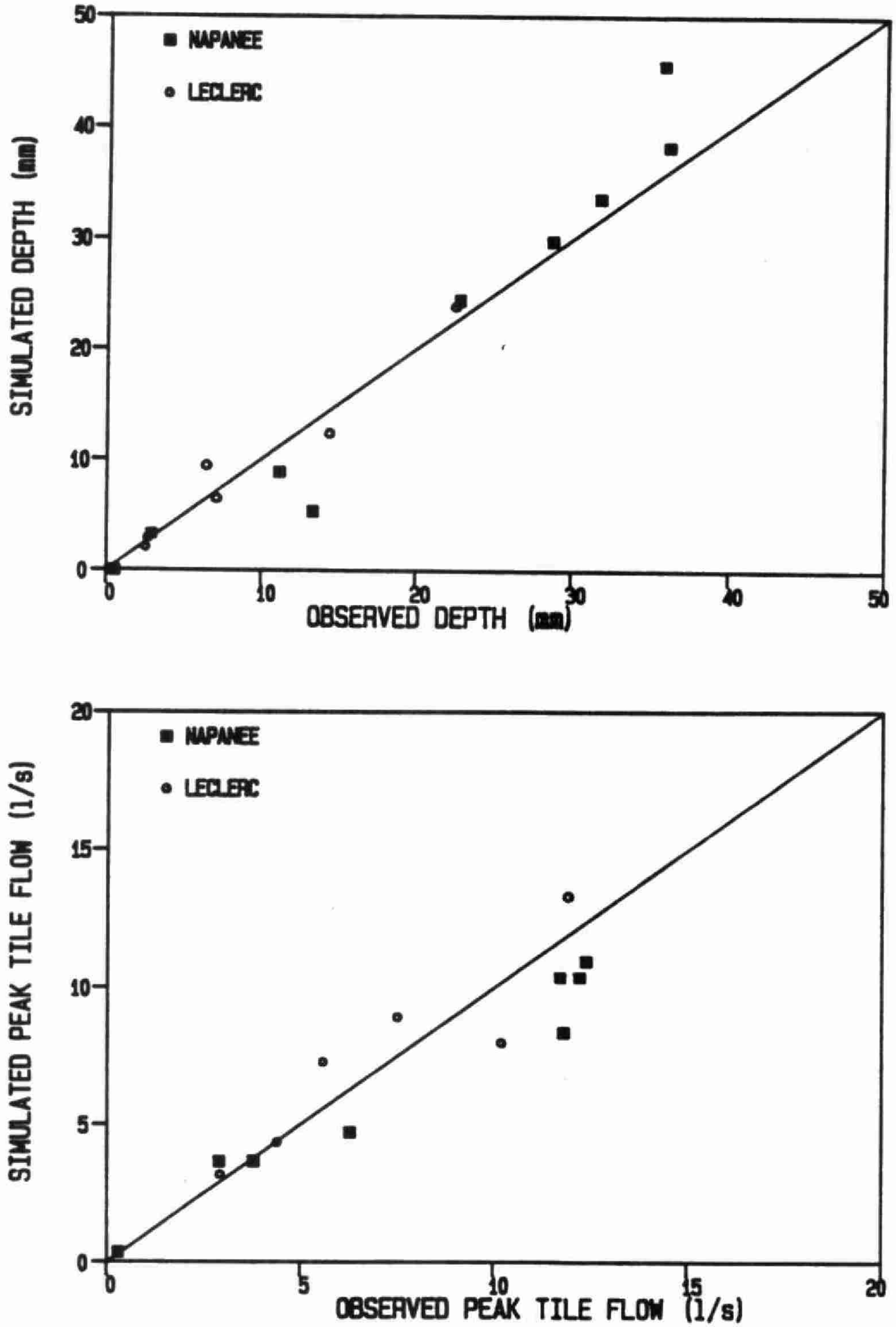


Figure 5-7 Observed and simulated depths and peak flows

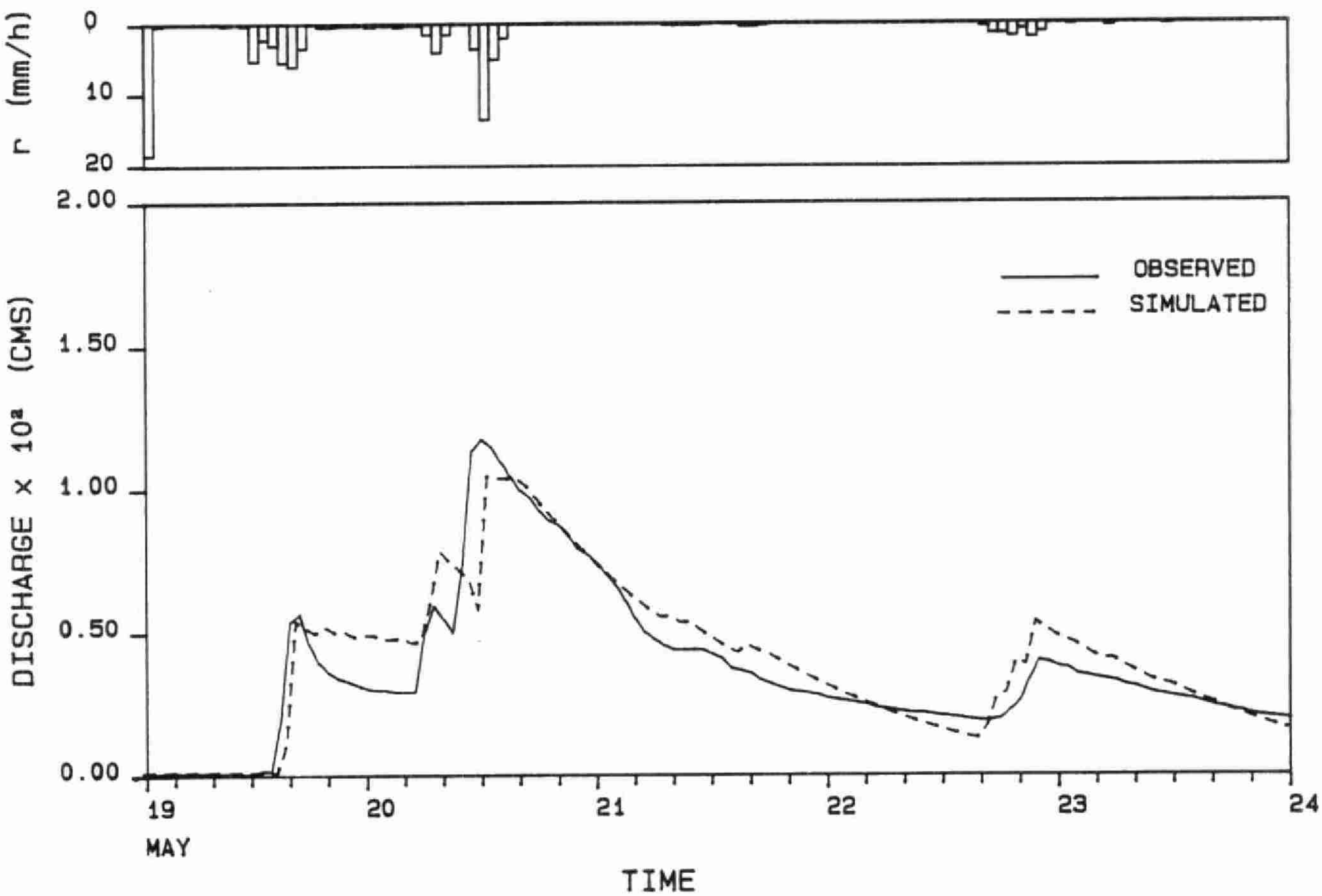


Figure 5-8 Observed and simulated hydrographs - Napanee Field

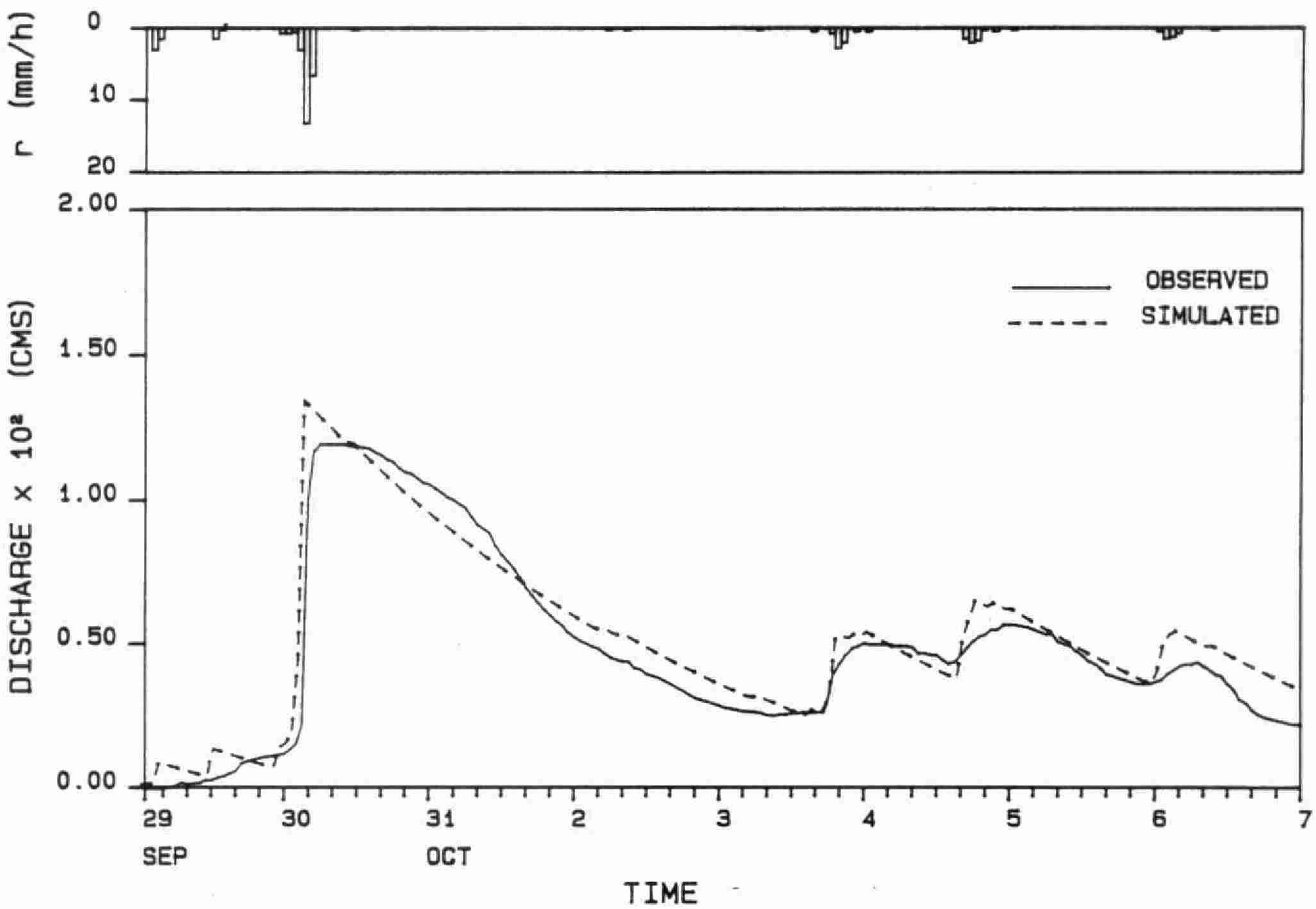


Figure 5-9 Observed and simulated hydrographs - Leclerc Field

Table 5.1 Field characteristics

Characteristics	Napanee Field	Leclerc Field
Tile Spacing (m)	12.2	16.8
Depth upper layer (mm)	300	300
Depth lower layer (mm)	700	700
Area (ha)	5.7	14.0

Table 5.2 Parameters of test fields

Parameter	Napanee Field	Leclerc Field
K_s (m/d)	0.3	1.0
μ	0.02	0.10
D (mm)	2	10
f_c (mm/h)	12	40
a	0.1	0.1
Depth impervious layer from tile axis (m)	1.5	0.85
Field capacity upper layer	0.25	0.17
Field capacity lower layer	0.45	0.17

5.7 Model Sensitivity

In addition to the calibration and verification exercises, the model was subjected to sensitivity tests to ensure that the sensitivity of the model to reasonable changes in parameters was compatible with the sensitivity of the real system to the same changes. Table 5.3 displays the parameters in order of their influence on tile flows for realistic changes in their values, the range over which the parameter was varied, and the range of the peak discharges and volumes in comparison to the final calibration run.

Initial Moisture Content

The model output and indeed the physical system is particularly sensitive to variations in the initial soil moisture content prior to a rainfall event. This observation is especially true for tight clay soils where the drainable porosity is very small relative to the field capacity. A large volume of water may be absorbed with little or no tile flow as the soil moisture content is brought to field capacity - following this a small additional input will yield a rapid increase in groundwater table and in tile discharge. The effect of uncertainty in initial soil moisture content lessens as the simulation proceeds; the effects become small after approximately 2 days of simulation.

Hydraulic Conductivity

The model output is sensitive to changes in hydraulic conductivity. Doubling this parameter will approximately double the tile flow and increase the volume of tile flow by 20 percent. For this reason, it is particularly important to determine K_s as accurately as possible for any application of the model.

Table 5.3 Sensitivity of tile model to parameter changes

Parameter	Range	Q_p as percentage of calibrated value	Volume as percentage of calibrated value
Initial soil moisture content	±30%	40 - 140	45 - 160
K_s	x 2 & x 1/2	40 - 190	70 - 120
μ	±25%	80 - 140	90 - 115
Depth to impervious layer	±0.5 m	75 - 115	90 - 104
Depth of upper soil zone	±100 mm	98 - 105	90 - 110
f_c	x 3 & x 1/3	80 - 100	85 - 100

Drainable Porosity

Although equilibrium tile flow (water table at surface) will not be affected by changes to the drainable porosity, all flows lower than equilibrium flow will be affected. A lower drainable porosity for a constant K_s will increase tile flows; in addition the shape of the recession which is related to $K_{s/\mu}$ will change. A higher K_s/μ ratio will decrease the recession constant of the tile flow hydrograph.

Depth to Impermeable Layer

Variations in the depth to the impermeable layer will be similar to alterations in the hydraulic conductivity as the effect is to change the cross sectional area of the flow to the tiles. For depths to the impervious layer in excess of approximately 1 m, changes in this parameter will produce little effect on the tile flow as the effective depth to the impermeable layer approaches a constant.

Depth of the Upper Soil Zone

The upper soil layer represents the layer of disturbed soil which is usually higher in total porosity and hydraulic conductivity than the undisturbed soil beneath. As this upper zone permits a temporary moisture storage before allowing water to percolate, changes in its thickness have a similar effect on the tile flow as changes in its initial moisture content. The shape at the commencement of the tile flow hydrograph is affected. For the two test fields where the upper zone characteristics were not appreciably different from the lower horizons, altering the thickness of the upper layer had little effect on the larger flow events.

Ultimate Infiltration Capacity

A lower f_c will prevent excess moisture from entering the soil. A portion of this excess may be held in the depression storage and hence delay its entry into the soil. Also, if the depression storage should fill, excess water will be lost from the system via surface flow. Because of this process, variations in f_c will affect the peak flows, the total volumes of tile flow and the shape of the tile discharge hydrograph. Because both fields were not particularly sensitive to f_c this parameter has been set equal to the hydraulic conductivity.

5.8 Estimation of Parameters and Model Applications

Because of the relatively few parameters required and because of their physical basis, the model should be relatively easy to apply to uninstrumented fields for purposes of the design or assessment of tile drainage systems. Table 5.4 identifies the key model parameters and suggests their method of estimation for uninstrumented fields.

Table 5.4 Estimation of model parameters

Parameter	Typical Range	Method of Estimation
Diameter of Tiles	50 - 250 mm	Measurement
Spacing of Laterals	5 - 20 m	Measurement
Slope of Field	0.001 - 0.1 m/m	Measurement and calculation
Hydraulic Conductivity	0.01 - 10 m/d	Auger hole method or Guelph permeameter or typical literature values
Depth of Impermeable Layer	0.5 - 5 m	Measurement, or soil maps
Drainable Porosity	1 - 15%	Literature values
Depression Storage	2.0 - 25 mm	Literature values and qualitative assessment
Initial Moisture Content	0.05 - 1.0	Field capacity for design purposes (literature values)
Depth of Upper Layer	0 - 300 mm	Measurement
Vegetation Parameter in Holtan's equation	0.1 - 1.0	Literature values
Ultimate Infiltration Capacity	0.5 - 100 mm/h	same as K_s

6.0 SMALL BASIN MODEL

Following the development and calibration of the tiled field simulation model, the model was extended to permit the simulation of a small agricultural basin. Channel routing algorithms for field ditches and main drains were developed to route and add flow from individual tiled or untiled fields. The output from the small basin model reflected the effects of the channel lags on the hydrograph at the outlet of the small basin.

To assist in the development of the small basin model, an agricultural subbasin was selected on Wilton Creek approximately 5 km from the gauged Napanee Field (Figure 6-1). This subbasin consists of approximately 20 agricultural fields and composes an area of 168 ha. Of the 20 fields, about 40 percent are tile drained.

6.1 General Structure of Model

The model structure as depicted in Figure 6-2 consists of nodes linked by channel elements. Outflow hydrographs from the individual agricultural fields are input at the nodes where they become input to the channel element. To simplify the modelling, minor surface ditches are not necessarily modelled with the channel elements, but may be handled through the surface routing algorithm of the field simulation model.

6.1.1 Channel Routing Algorithm

The channel element in the small basin model employs a simple lag based on the channel cross section, slope and roughness (Hulley 1986). The channel lag time is estimated using an approximation of the expected peak flow and Manning's equation. Expected peak flow for an event is generated based on an application of the rational method using the area upstream of the channel element and using the maximum hourly precipitation for the day. Once the expected flow is determined the application of Manning's equation permits the calculation of expected channel velocity and hence the lag time for the channel element.

[17] $$t_L = L/_{Ve}$$

6.1.2 Reservoir Routing

Reservoir routing is included in the model to account for the attenuation of peak flows which may be experienced as a result of storage in rural ponds or in the channel itself. The reservoir routing algorithm uses the conventional modified Puls solution technique.

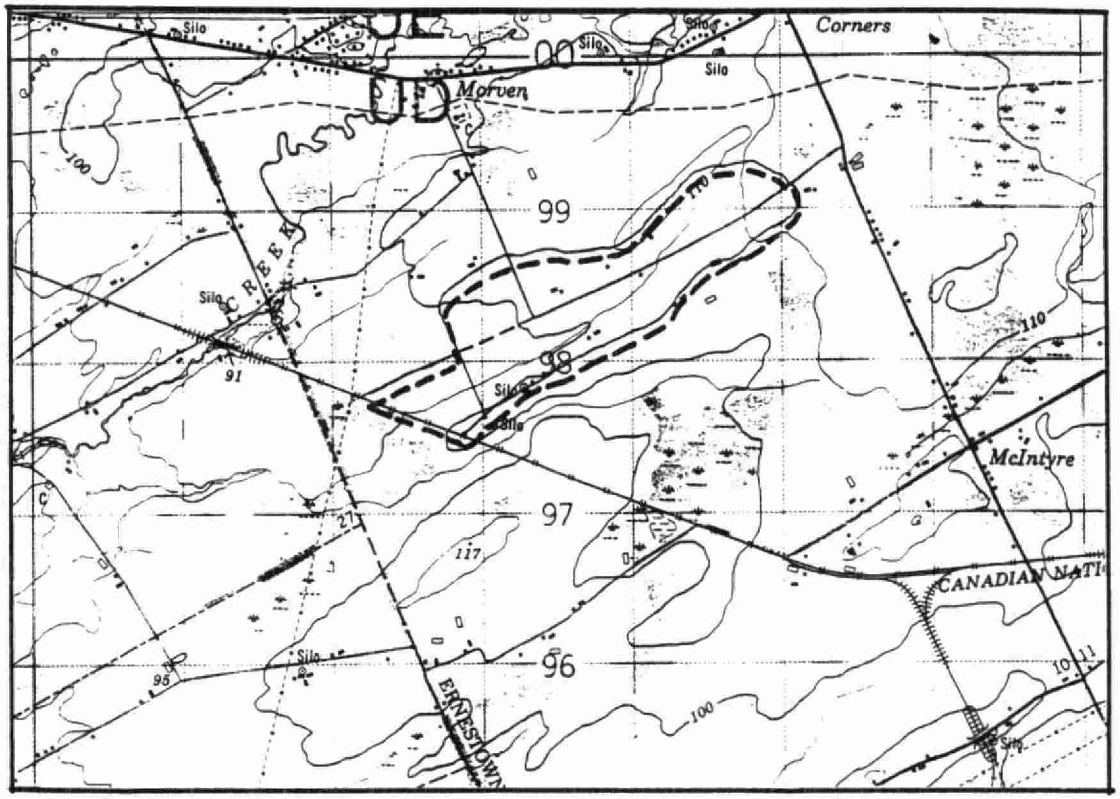


Figure 6-1 The Wilton Creek subbasin

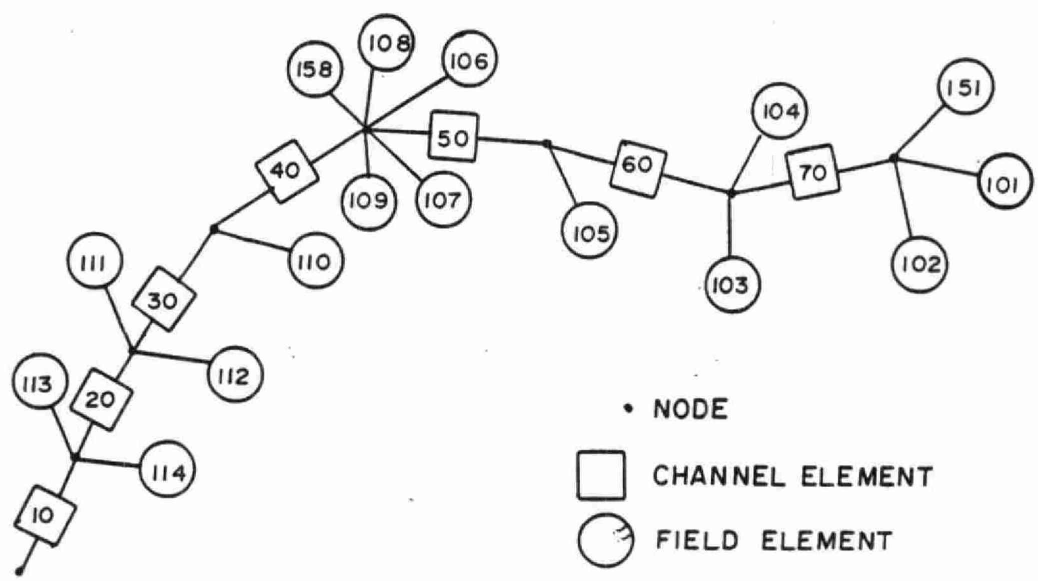


Figure 6-2 Basin model schematization

7.0 IMPACTS OF DRAINAGE ON PEAK AND LOW FLOWS

7.1 Impacts at Field Level

Following the development of the field model, use was made of the model to infer the effects of drainage at the field level. The tiled fields were compared with a hypothetical untiled situation, wherein the tiles were replaced by parallel drainage ditches at larger spacings (typically 5 to 10 times the tile spacing). The tile flow algorithm in the model is still applicable for the case.

7.1.1 Event Basis

The behaviour of tiled and untiled fields with different soil types was first compared on an event basis. Two hypothetical fields were defined, based on the findings of the Napanee and Leclerc fields (Tables 7.1 and 7.2).

To allow convenient comparison, the tile spacing of the sandy soil field and that of the clay soil has been designed based on a common drainage coeffficient of 18 mm/day (equilibrium tile flow with water table at surface). With all four fields (sandy, clay, drained and undrained) initially at field capacity, three rainfall patterns were simulated:

i) two days of constant rainfall at 2 mm/h for a total of 48 mm,
ii) ten days of constant rainfall at .25 mm/h for a total of 60 mm, and
iii) three independent events seven days apart with 30 mm each day (1.25 mm/h).

Table 7.1 **Field 1 - Sandy soil characteristics and parameters**

Parameter or Characteristic	Drained Case	Undrained Case
K_s (m/d)	2.0	2.0
μ	.10	.10
D (mm)	5.0	5.0
f_c (mm/h)	83	83
Depth Impervious layer from tile/ditch axis (m)	1.0	1.0
Field capacity upper layer	.15	.15
Field capacity lower layer	.15	.15
Tile/ditch spacing (m)	33.6	336.0
Depth upper layer (mm)	300	300
Depth lower layer (mm)	700	700
Area (ha)	100	100

Table 7.2 Field 2 - Clay soil characteristics and parameters

Parameter or Characteristic	Drained Case	Undrained Case
K_s (m/d)	0.2	0.2
μ	.02	.02
D (mm)	5.0	5.0
f_c (mm/h)	8.3	8.3
a	.1	.1
Depth Impervious layer from tile/ditch axis (m)	1.0	1.0
Field capacity upper layer	.25	.25
Field capacity lower layer	.45	.45
Tile/ditch spacing (m)	9.3	336
Depth upper layer (mm)	300	300
Depth lower layer (mm)	700	700
Area (ha)	100	100

Daily temperatures experienced during June of 1986 for Kingston, Ontario, were used to drive the evapotranspiration model during the events.

High Intensity Rainfall Event

The effects of a relatively high intensity rainfall on the drained and undrained sand and clay soils are shown in Figure 7-1. Particularly noticeable is the lack of surface runoff from the sandy soil in either the drained or undrained state.

The tile drainage on both soils is very similar with respect to its impact on the groundwater table; the impacts differ, however, regarding runoff to receiving water bodies. The tile drainage in the sand removes the excess water rapidly; while in the case of clay soil, the tile drainage attenuates the surface flow and slightly extends the duration of the combined runoff hydrograph.

Long Duration Low Intensity Rainfall Event

Figure 7-2 depicts the hydrographs and water tables resulting from a 10 day duration constant rainfall of total depth 60 mm.

The impact of drainage on the hydrograph to the receiving water body on the clay soil is small; the surface flow in the undrained case is replaced by subsurface flow in the drained field. The most noticeable difference occurs in the sandy soil, where the action of drainage increases the peak flow to the tile outlet. Although the drainage coefficient for both drained soils has been fixed at 18 mm/day, the additional storage in the sandy soil results in lagging and attenuation of the drained hydrograph over that of the drained clay soil.

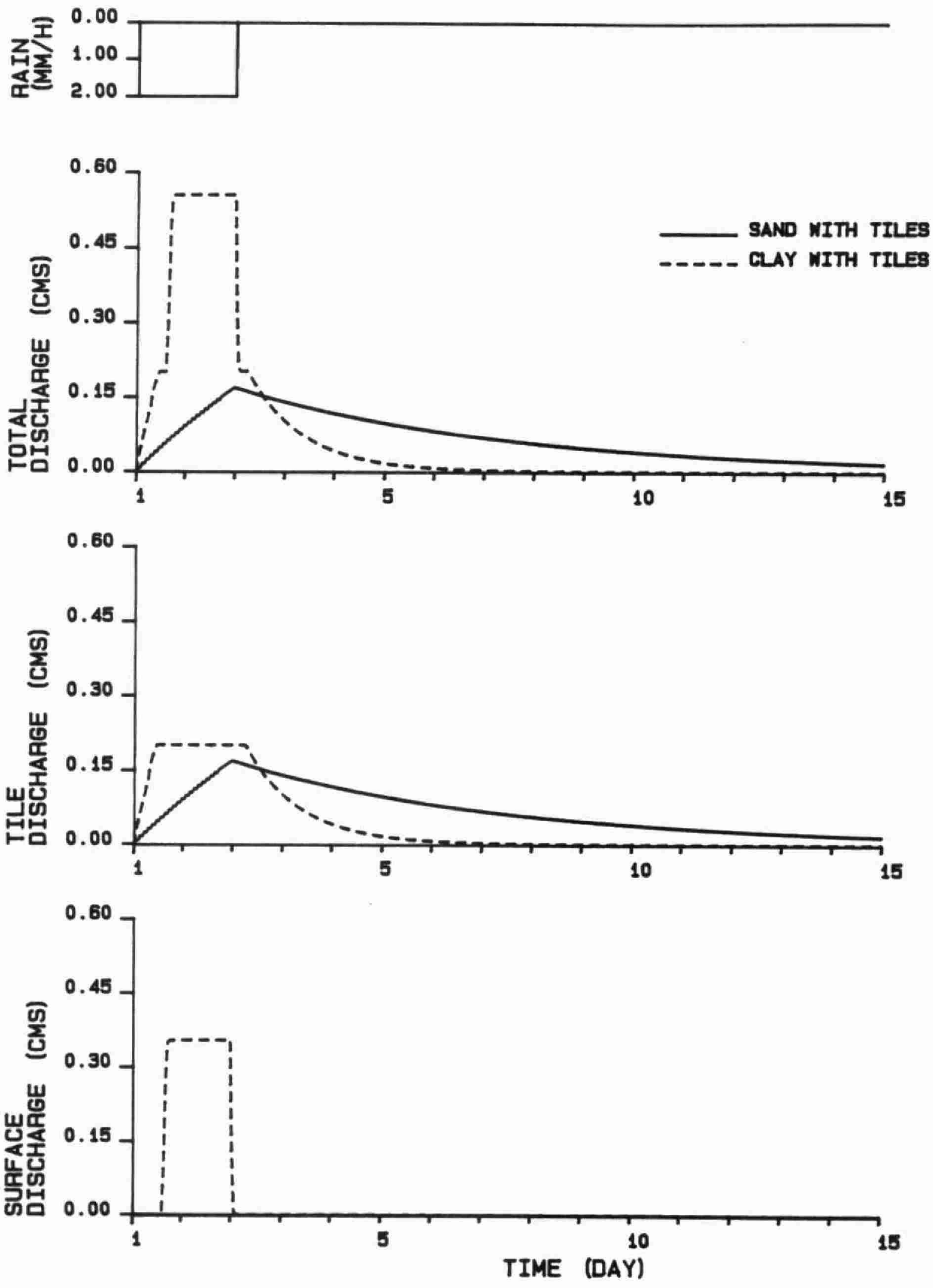


Figure 7-1a Effect of high intensity rain event - tiled field

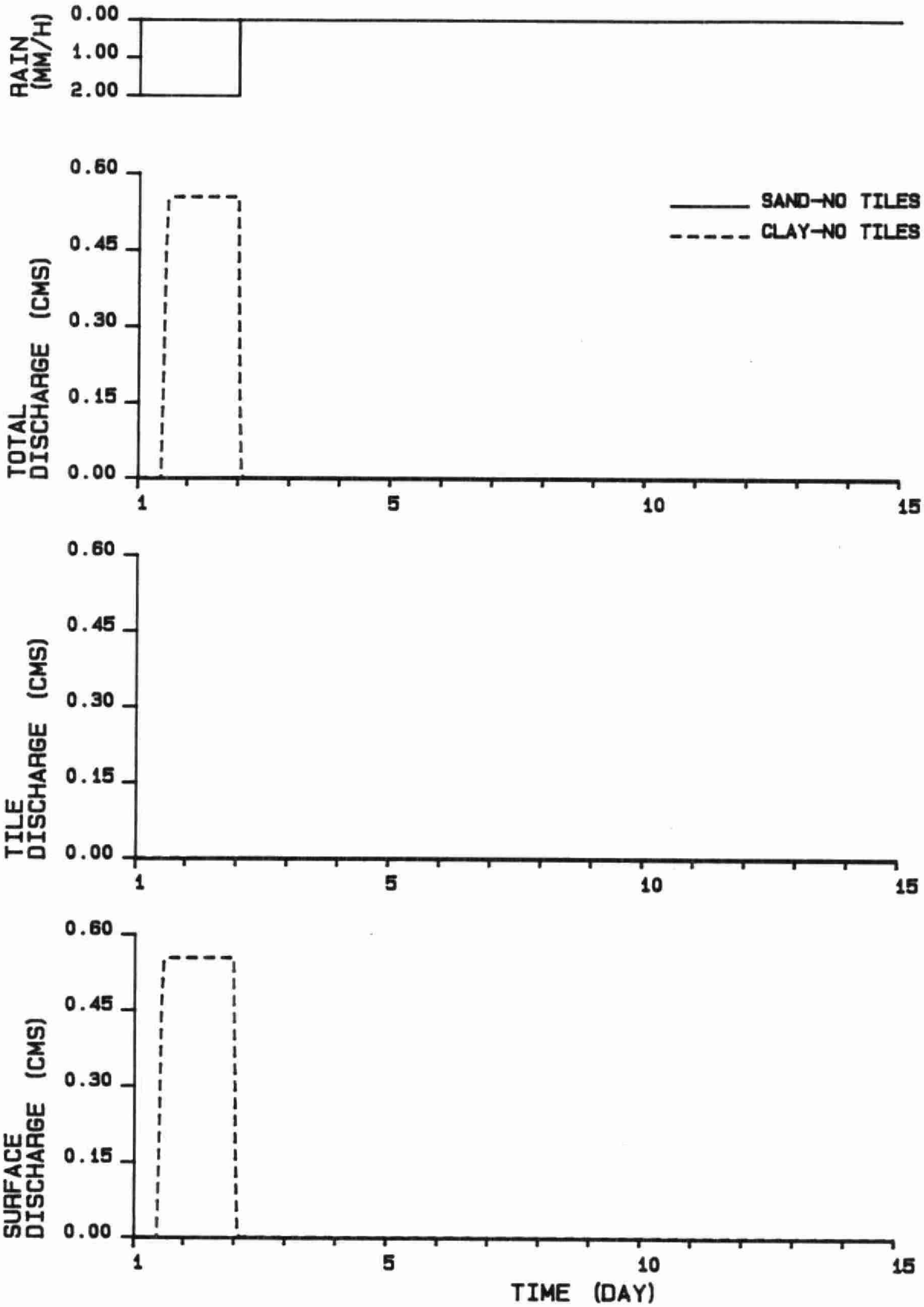


Figure 7-1b Effect of high intensity rain event - untiled field

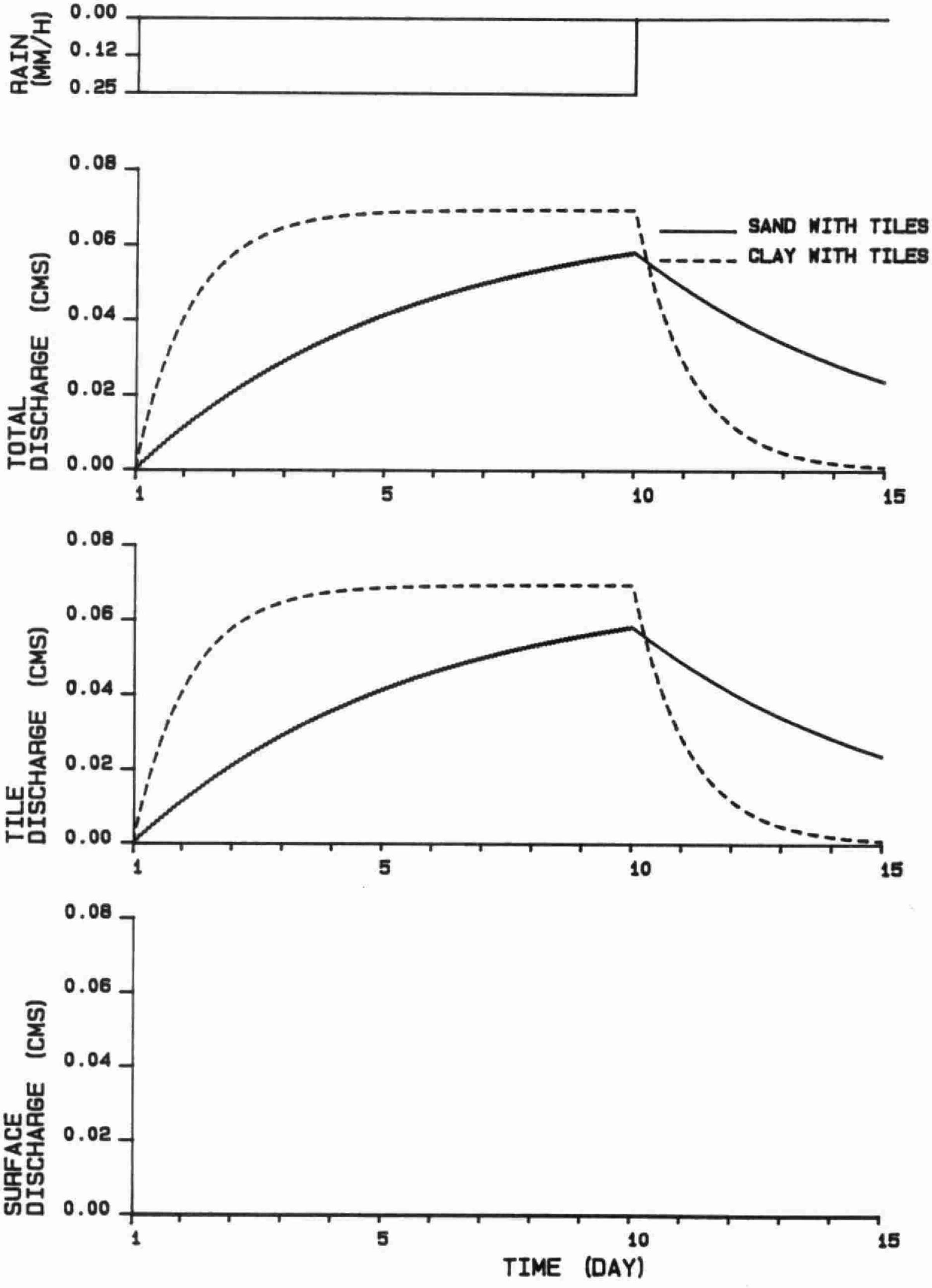


Figure 7-2a Effect of long duration rainfall - tiled field

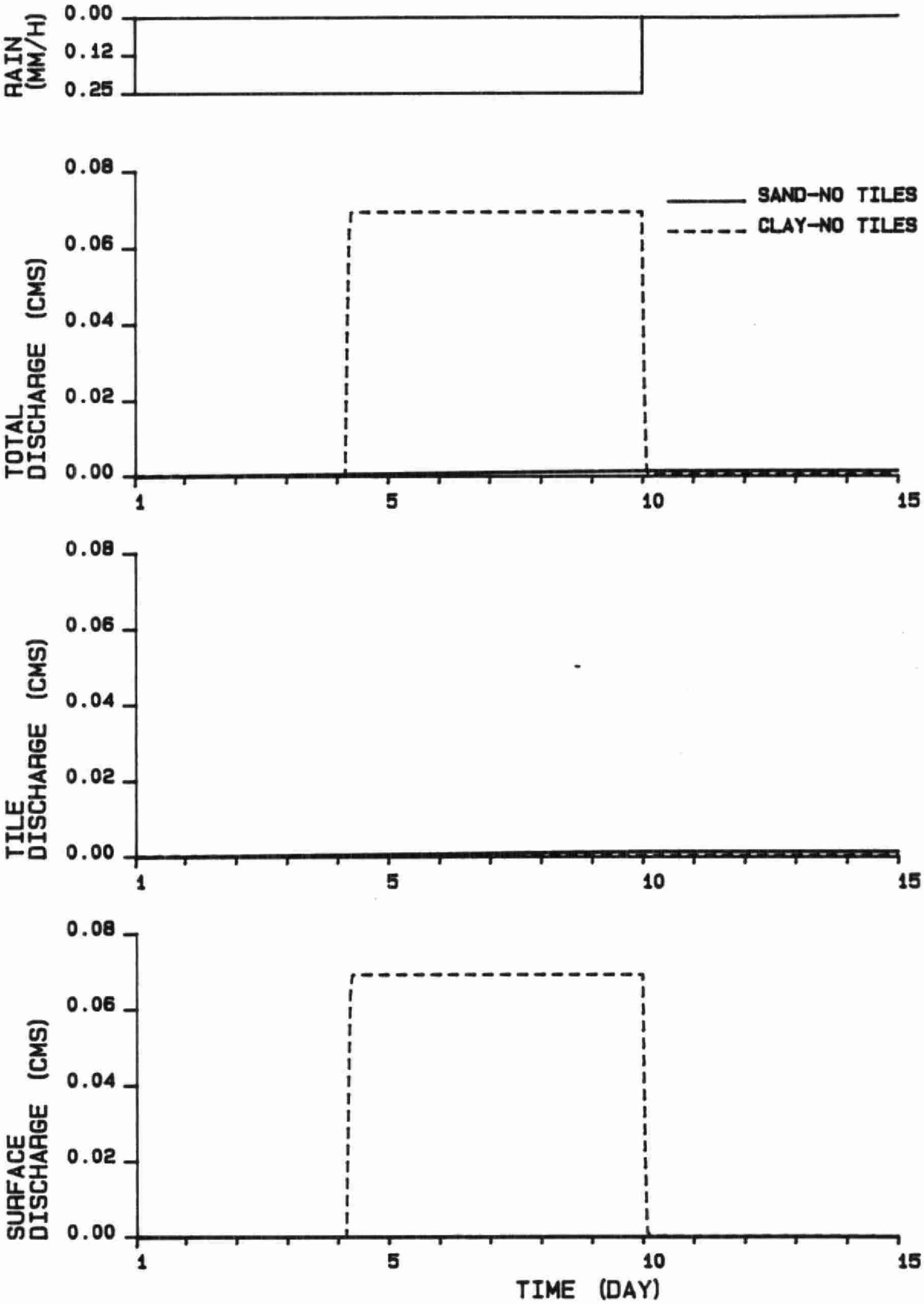


Figure 7-2b Effect of long duration rainfall - untiled field

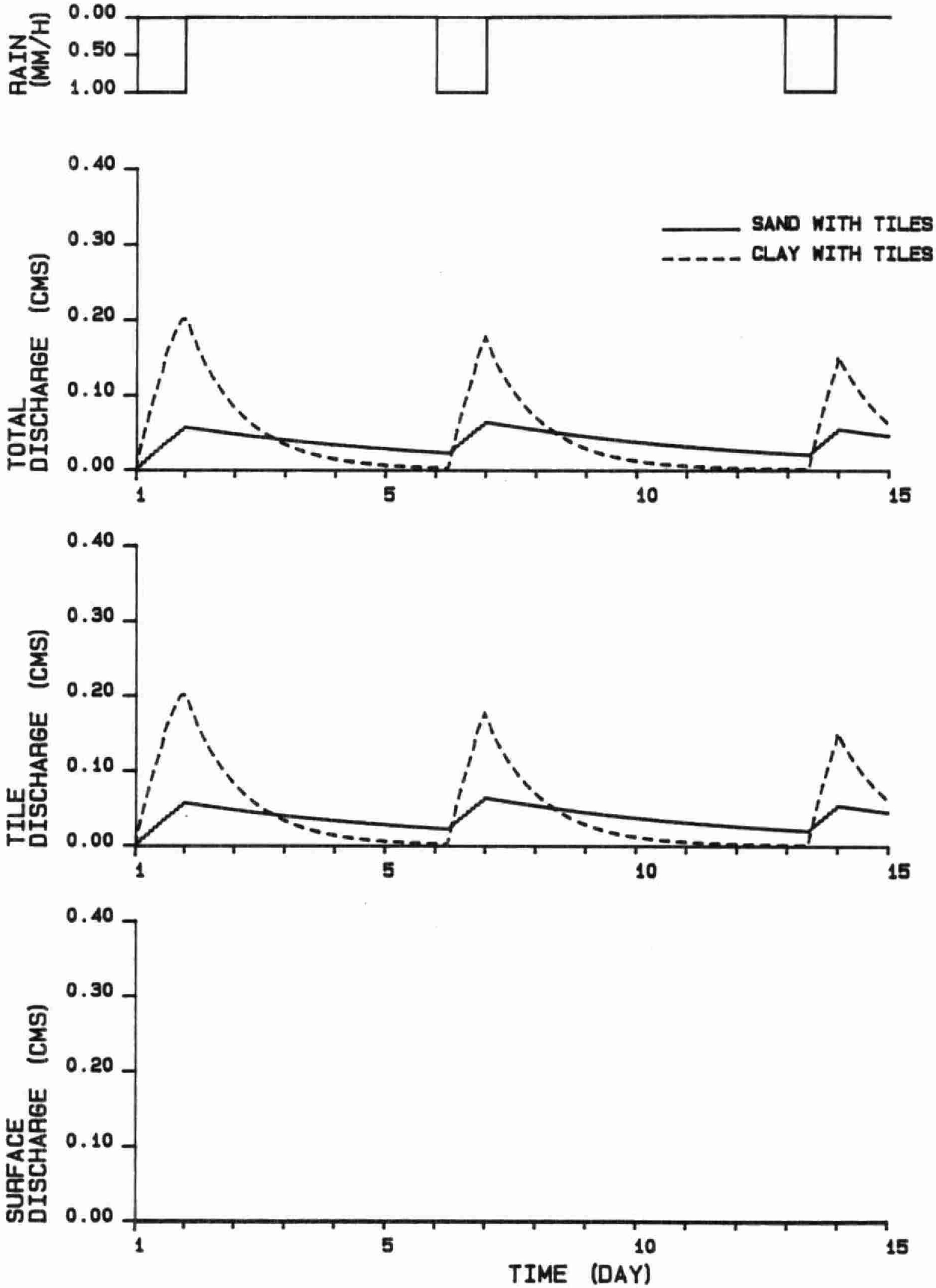
Three Rainfall Events in Succession

As in the earlier heavy rainfall event, surface runoff exists only in the undrained clay soil (Figure 7-3). Draining of this soil removes the surface flow from these events and replaces it with an attenuated tile flow. Draining the sandy soil increases the peak flow from the field, although the peaks are considerably lower than that for the clay soil. The effect of evapotranspiration is apparent with the clay soil where each succeeding peak is smaller than the previous one. Evapotranspiration lowers the moisture content of the soil profile below field capacity between events.

7.1.2 Seasonal Impacts of Tile Drainage on Fields

Because the hydrologic response of an agricultural field, whether tiled or not, is heavily influenced by antecedent moisture conditions, it is impossible to assess drainage impacts on peak or low flows through the examination of single events. Antecedent moisture conditions are a function of the drainage intensity and the prevailing climate (temperature and rainfall) prior to the event of record. In order to assess quantitively the impacts of tile drainage on peak and low flows, it is necessary to examine the hydrologic response of tiled and otherwise physically identical untiled fields over a season.

To determine these impacts as realistically as possible, the seasonally calibrated runs for the Napanee and Leclerc fields have been used to define the hydrologic response of drained field respecting peak flows and low flows to receiving water bodies. As identical untiled fields have not been monitored, if in fact they exist, the model has been used to simulate these fields in an undrained condition for the same meteorological input. This undrained condition has been simulated by assuming ditch drainage along the field boundaries, resulting in an effective ditch



Figures 7-3a Effect of three successive rainfall events - tiled field

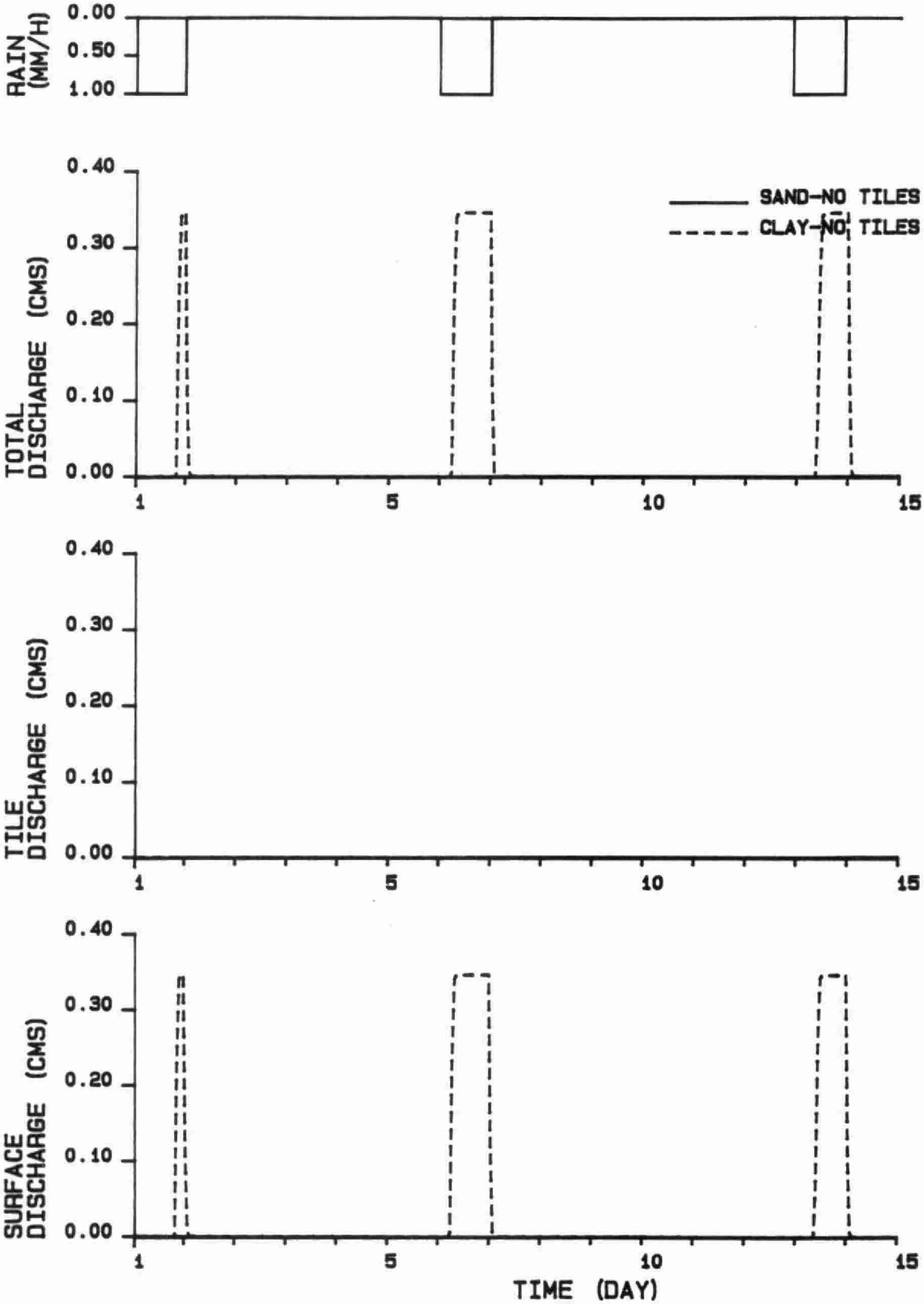


Figure 7-3b Effect of three successive rainfall events - untiled field

spacing for the Napanee field of 100 m and for the Leclerc field of 90 m.

Monthly Flows

Tables 7.3 and 7.4 depict the monthly hydrologic response for the drained and undrained situations for the Napanee field and the Leclerc field. It can be seen from these tables that the modelled evapotranspiration is very similar for both the tiled and untiled situations and as a result the total runoff volumes for both cases are similar. The key difference between the tiled and untiled cases is the shift between surface runoff and subsurface runoff. For the untiled case, the limited capacity of the ditches to remove subsurface flow rapidly forces the water table to the surface where excess water is removed via surface flow.

Table 7.3 Napanee field - Monthly hydrologic response for tiled and and untiled field - 1986

Month	Tiled Field			Untiled Field		
	Surface Runoff (mm)	Sub-surface Runoff (mm)	Evapo- transpiration (mm)	Surface Runoff (mm)	Sub-surface Runoff (mm)	Evapo- transpiration (mm)
April	0	21.6	24.2	0	5.1	24.2
May	18.2	45.6	43.8	52.7	8.8	43.8
June	3.6	40.3	51.0	37.2	9.3	51.0
July	0	0	73.3	0	6.4	73.3
Aug	4.2	10.2	67.0	4.6	6.6	67.0
Sept	21.7	88.7	36.4	95.5	10.5	36.4
Oct	0	55.3	21.2	35.3	12.2	21.2

Table 7.4 LeClerc field - Monthly hydrologic response for tiled and untiled field - 1986

Month	Tiled Field: Surface Runoff (mm)	Tiled Field: Sub-surface Runoff (mm)	Tiled Field: Evapo-transpiration (mm)	Untiled Field: Surface Runoff (mm)	Untiled Field: Sub-surface Runoff (mm)	Untiled Field: Evapo-transpiration (mm)
May	0	16.0	36.0	0	2.2	36.0
June	0	.3	57.4	0	5.2	57.4
July	0	14.6	64.5	0	7.8	70.7
Aug	0	0	44.6	0	1.5	52.2
Sept	0	21.6	37.7	0	4.9	37.7
Oct	0	62.4	18.8	18.8	21.9	18.8

Flow Duration Curves

The seasonal effects of tile drainage have been assessed using flow duration data. Flow duration data for the 1986 season is defined in Tables 7.5 to 7.7 and illustrated in Figures 7-4 and 7-5.

These curves express the intensity of total runoff (both surface and subsurface runoff) in millimeters per hour versus the percentage of time the indicated intensity is equalled or exceeded. Using the Napanee flow duration curve as an example (Figure 7-4), for 50% of the time, runoff intensity in the tiled field would equal or exceed 0.04 mm/h. The runoff intensity for the undrained case would equal or exceed 0.14 mm/h, 50% of the time. The impacts of tile drainage on the Napanee field are well illustrated by the flow duration curve, which can be divided into three distinct areas. Area C illustrates the effect tile drainage has on the low flows, an efficient tile drainage system removes the excess moisture

storage in the soil profile quickly whereas an untiled field will provide a longer sustained interflow. The result is that the low flow periods will be increased when a field is tiled. Area B illustrates that for a smaller period of time and for intermediate flows below the equilibrium tile flow, a tiled field will experience higher flows. This expresses the increased efficiency of the tiled system for removing moderate amounts of excess rainfall rapidly. Rainfalls of an intensity up to the equilibrium tile flow can be removed without surface runoff from a tiled field. Finally for a very small portion of time (Area A) and for flows in excess of the maximum tile drainage rate, it can be seen that high flows from the untiled field exceed those from the tiled field. This is a result of high intensity rainfalls which occur on saturated soil, thus producing surface runoff. As the soil profile is generally saturated or wetter for a longer period of time in the untiled field, which can only release water slowly through evaporation or interflow, any heavy rainfalls are more likely to produce surface runoff. A similar distribution of flows occurs for the South Nation test field when modelled in a tiled and untiled state, Figure 7-5, although the differences are smaller, likely as a result of the relatively pervious nature of the sandy soil in its natural state. In summary, for both fields, tiling has the effect of decreasing the number of high flows and increasing the duration of drought (very low) flows.

Both the number of events with surface runoff and the incidence of water tables in the root zone are increased for the untiled situations. This is particularly evident in the case of the clay soil of the Napanee field. Surface excess water in the root zone (upper 30 cm) is expressed as cumulative cm-days for each month in Table 7.8.

Skaggs (1978) indicates that although the SEW_{30} is a crude index, it nevertheless is a convenient method of approximating the quality of drainage. The general values during the growing season greater than 100-200 cm-days can be expected to decrease crop yields.

Table 7.5 Runoff intensity ranges for flow duration analysis

Range	Runoff Intensity mm/h
1	0
2	$0 < \chi \leq 0.01$
3	$0.01 < \chi \leq 0.10$
4	$0.10 < \chi \leq 0.50$
5	$0.50 < \chi \leq 1.0$
6	$1.0 < \chi \leq 3.0$
7	$3.0 < \chi \leq 5.0$
8	$\chi > 5.0$

Table 7.6 Annual distribution of runoff intensity for the Napanee field

Untiled

Range	Apr	May	June	July	Aug	Sep	Oct	Total	% Exceeded
				Number of Hours					
1	352	0	0	0	0	0	0	352	100
2	16	302	91	568	410	103	0	1490	93
3	352	410	609	176	332	570	710	3159	64
4	0	17	5	0	0	10	10	42	2.6
5	0	1	7	0	1	10	9	28	1.8
6	0	9	5	0	0	18	13	45	1.3
7	0	2	0	0	1	5	2	10	0.4
8	0	3	3	0	0	4	0	10	0.2

Tiled

Range	Apr	May	June	July	Aug	Sep	Oct	Total	% Exceeded
				Number of Hours					
1	352	0	0	0	0	0	0	352	100
2	170	566	544	744	589	342	329	3206	93
3	124	61	80	0	121	161	199	746	29
4	65	83	70	0	32	149	216	615	14
5	0	31	24	0	1	57	0	113	2.5
6	0	1	1	0	0	8	0	10	0.3
7	0	0	1	0	1	3	0	5	0.1
8	0	2	0	0	0	0	0	2	0.04

Table 7.7 Annual distribution of runoff intensity for the Leclerc field

Untiled

Number of Hours

Range	May	June	July	Aug	Sept	Oct	Total	% Exceeded
1	471	0	0	371	259	0	1101	100
2	198	720	299	373	180	0	1770	75
3	75	0	445	0	281	716	1517	35
4	0	0	0	0	0	14	14	0.6
5	0	0	0	0	0	7	7	0.3
6	0	0	0	0	0	7	7	0.2
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0

Tiled

Number of Hours

Range	May	June	July	Aug	Sept	Oct	Total	% Exceeded
1	471	0	239	744	264	0	1718	100
2	39	720	287	0	131	61	1238	61
3	183	0	177	0	276	400	1036	33
4	51	0	41	0	49	283	424	9.6
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0

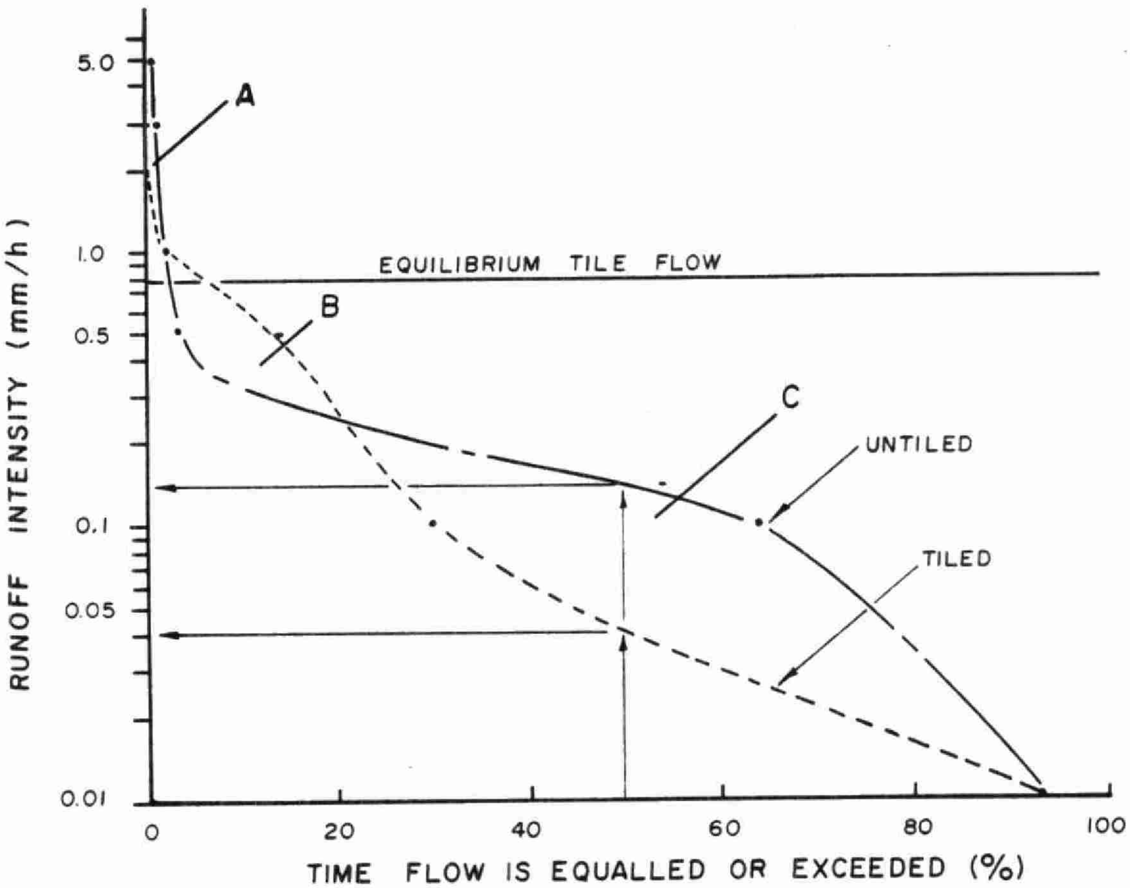


Figure 7-4 Flow duration curves Napanee field 1986 season for tiled and untiled cases

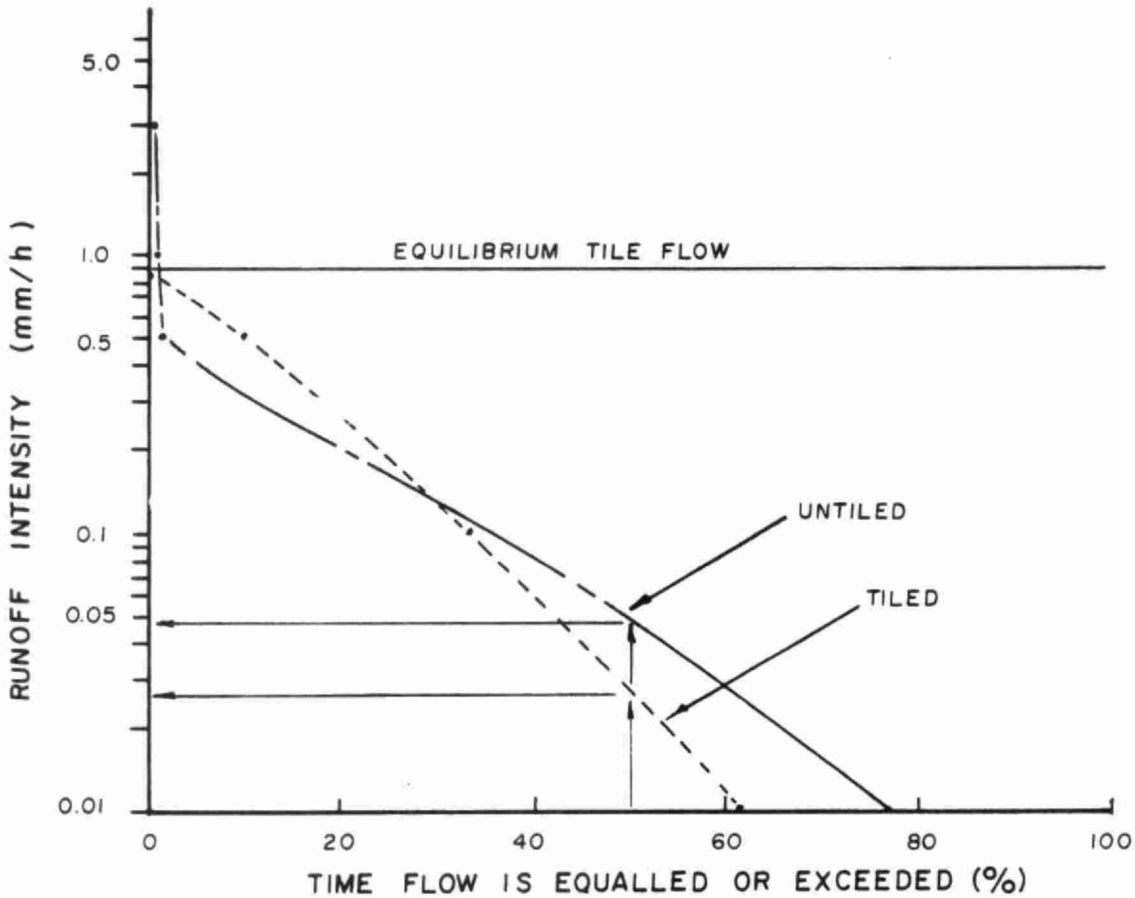


Figure 7-5 Flow duration curves Leclerc field 1986 season for tiled and untiled cases

Table 7.8 Excess water in root zone (cm-days) 1986 simulation

	Napanee Field		Leclerc Field	
Month	Tiled	Untiled	Tiled	Untiled
April	0	151		
May	24	216	0	0
June	10	205	0	0
July	0	0	0	0
Aug	0	0	0	0
Sept	51	488	0	5
Oct	0	678	0	646

7.2 Impacts at Small Basin Level

Impacts of drainage at the small basin level were assessed by the modelling of a small agricultural basin on Wilton Creek (Figure 6-1). The subbasin consists of twenty one fields ranging in size from 3 to 20 hectares for a total drainage of 168 hectares. Two soil types predominate in the basin, Napanee clay and Bondhead sandy loam. Corn, hay and soybeans are the principal crops. Nine fields with a total area of 74 ha (44% of total area) are presently tile drained. The watershed has been improved by ditching to link the fields into an efficient drainage network. Individual field elements are modelled using the field model as a subroutine. Field elements are added and hydrographs lagged appropriately to accommodate travel times in the channels. With the meteorological data from the summer of 1986, three physical situations were appraised for the subbasin. These were the existing level of drainage, the basin with no tile drainage, and a maximum level of tile drainage.

Peak Flows

The effect of the alterations on modelled peak flows is displayed in Table 7.9 for the eight largest events in the season. Also noted in Table 7.9 are the peaks with the channel lags removed. In every instance increasing the area tiled reduces the peak flows at the basin outlet, with a reduction in flow peaks of up to 80% for the maximum tiled case over the no tiles situation. Removing the channel lags has very little effect on the peak flows, indicating that changes at the field level provide greater impacts than improvements to the efficiency of the ditch network. Ditches in other areas of Ontario where substantial storage exists in the ditch network may provide more significant impacts than in the Napanee area where ditch storage is negligible.

Figure 7-6 illustrates the storm of September 11, 1986 (90.4 mm of rainfall) for the three levels of tile drainage modelled. It is noted that the maximum tile drainage situation attenuates the peak outflow of the subbasin by over 80%. Also shown on the figure for comparison is the discharge level from the subbasin which would be compatible with a typical drainage coefficient of 18 mm /day (.75 mm/h).

Low Flows

Although peak flows are attenuated with tile drainage, which may provide some flood relief to receiving water bodies, low flows are aggravated. Average flows during the month of July are .00053 m^3/s, .00098 m^3/s and 0.0 m^3/s for the no tiled case, the existing case and the maximum tiled situation respectively. The existing situation with 40% of the area tiled has low flows in the order of 50% of that which would occur with no tiles, while the maximum possible tiled case has no flow during the month of July.

Table 7.9 Small basin model results - peak flows

Event	No tiles (m^3/s)	Existing drainage (m^3/s)	Maximum drainage (m^3/s)
May 20	1.9	1.9	1.4
	(1.9)	(2.0)	(1.6)
June 12	1.5	1.2	.49
	(1.9)	(1.5)	(.48)
August 8	.41	.36	.24
	(.47)	(.45)	(.38)
Sept 11	2.6	2.0	.74
	(2.5)	(1.9)	(.74)
Sept 15	.58	.43	.12
	(.57)	(.41)	(.12)
Sept 23	2.1	1.5	.42
	(2.1)	(1.4)	(.51)
Sept 30	.92	.66	.23
	(.75)	(.70)	(.23)
Oct 14	.60	.43	.14
	(.60)	(.42)	(.14)

* Figures in brackets represent the output with no consideration of channel lag times

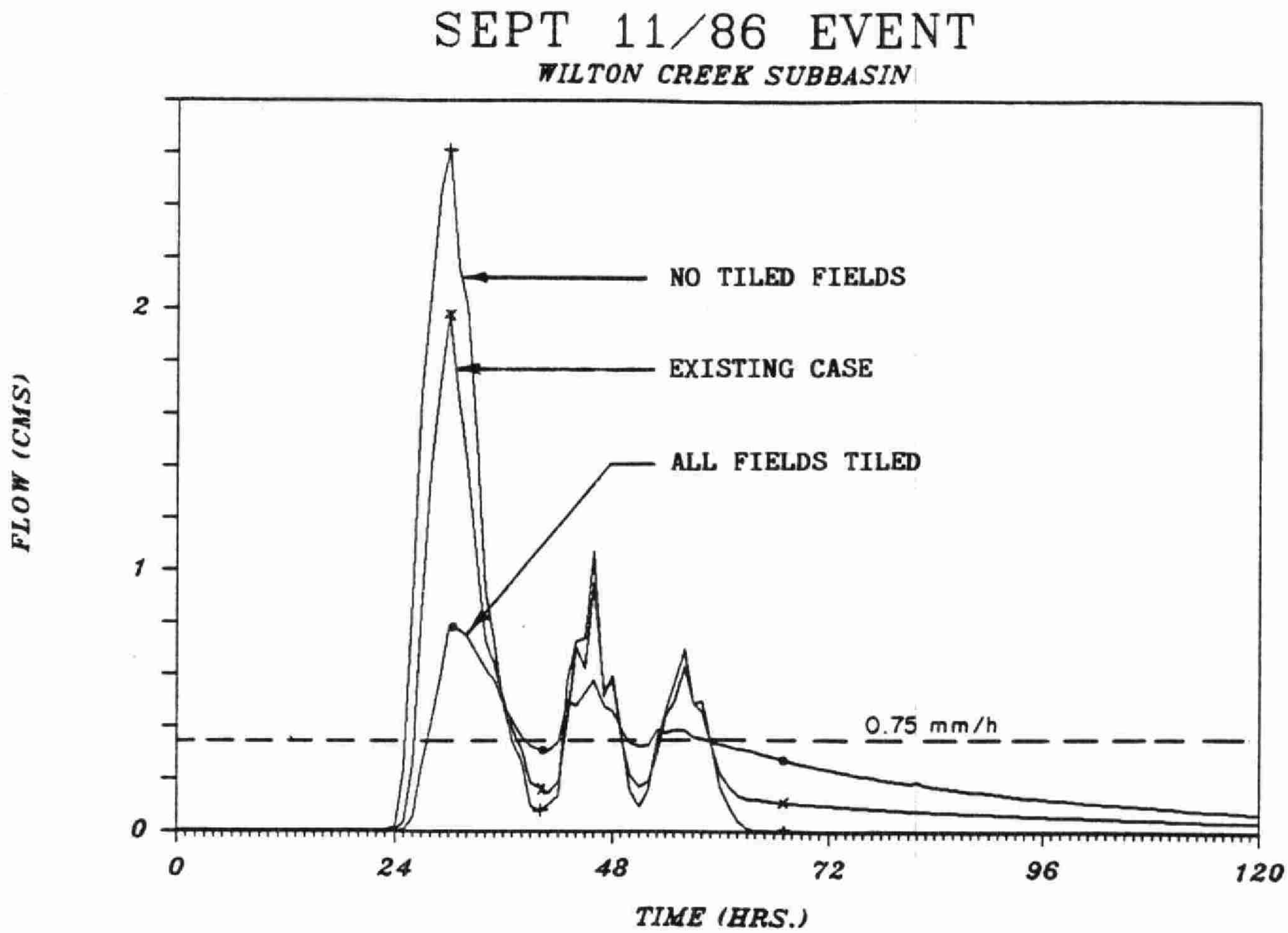


Figure 7-6 The effect of various levels of tile drainage on the basin response to a rainfall event

8.0 SUMMARY AND RECOMMENDATIONS

A model capable of reproducing the hydrological processes of a tile drained field has been developed, calibrated and verified on two fields in southern Ontario. The model, which is capable of running in a continuous mode on a personal computer, possesses physically-based parameters which for the most part can be relatively easily determined independent of the model itself. The overall performance of the model with respect to reproducing flow peaks, volumes and hydrograph shapes is excellent.

The model, in its continuous mode, was used to assess the impacts of tile drainage systems on peak and low flows at the field level and at the small basin level. The application of the model to the test fields and the statistical examination of meteorological data and streamflow data led to the following conclusions regarding the impacts of agricultural drainage in Ontario.

- Statistically significant evidence of the impact of tile or ditch drainage on streamflows is extremely difficult to obtain. An examination of flow records for trend indicates that alterations to the flow series as a result of climatological trends far overshadows any lesser trends which may come about as a result of drainage activity.

- The hydrologic response of a tile drained field is particularly sensitive to antecedent moisture conditions prior to rainfall events. Because the tile drained system affects the soil water balance and hence the antecedent conditions in a field, it is impossible to comment on the impacts of tile drainage through an examination of

independent rainfall events. It is necessary to consider seasonal periods to establish the changes in the frequency of various surface or subsurface hydrograph peaks and volumes.

. A simple deterministic hydrologic model can, when calibrated, be used successfully to assess the impacts of tile drainage on peak and low flows for various field characteristics and soil types.

. Tile drainage in southeastern Ontario does affect peak and low flows. In general, draining exacerbates low flow periods during summer months (July and August) and reduces the frequency of high flows as a result of intense rainfall events.

. Tile drainage does not significantly change the total volume of runoff, but the relative magnitudes of surface and subsurface runoff are significantly changed. The subsurface flow, which would be interflow in the untiled case and largely tile flow in the tiled field, is increased significantly for tiled fields. Because of this alteration in flow paths to receiving streams, it is expected that other processes requiring water as a transport medium will be altered significantly. These processes could include soil erosion, nutrient runoff, and herbicide and insecticide transport and decay mechanisms.

It is recommended that:

. to extend the use of the model to other areas of Ontario, efforts should be concentrated on relating the required model parameters to published (readily available) information on soil types and land use;

. the model be linked to water quality algorithms to assess the impacts of drainage activity on water quality in receiving streams;

- additional work, including calibration and verification at the small basin level to test the robustness of the model when integrating several agricultural fields (both tiled and untiled, and crop and pasture land uses); and

- the model and other information be disseminated to other government agencies as it becomes available with a view to ultimately applying the information in a practical manner for land use assessment or tile drainage design.

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